Better Weather Forecasts Resulting from Improved Land Surface Processes in EC's Numerical Prediction Systems

Stéphane Bélair

Meteorological Research Division
Environment Canada
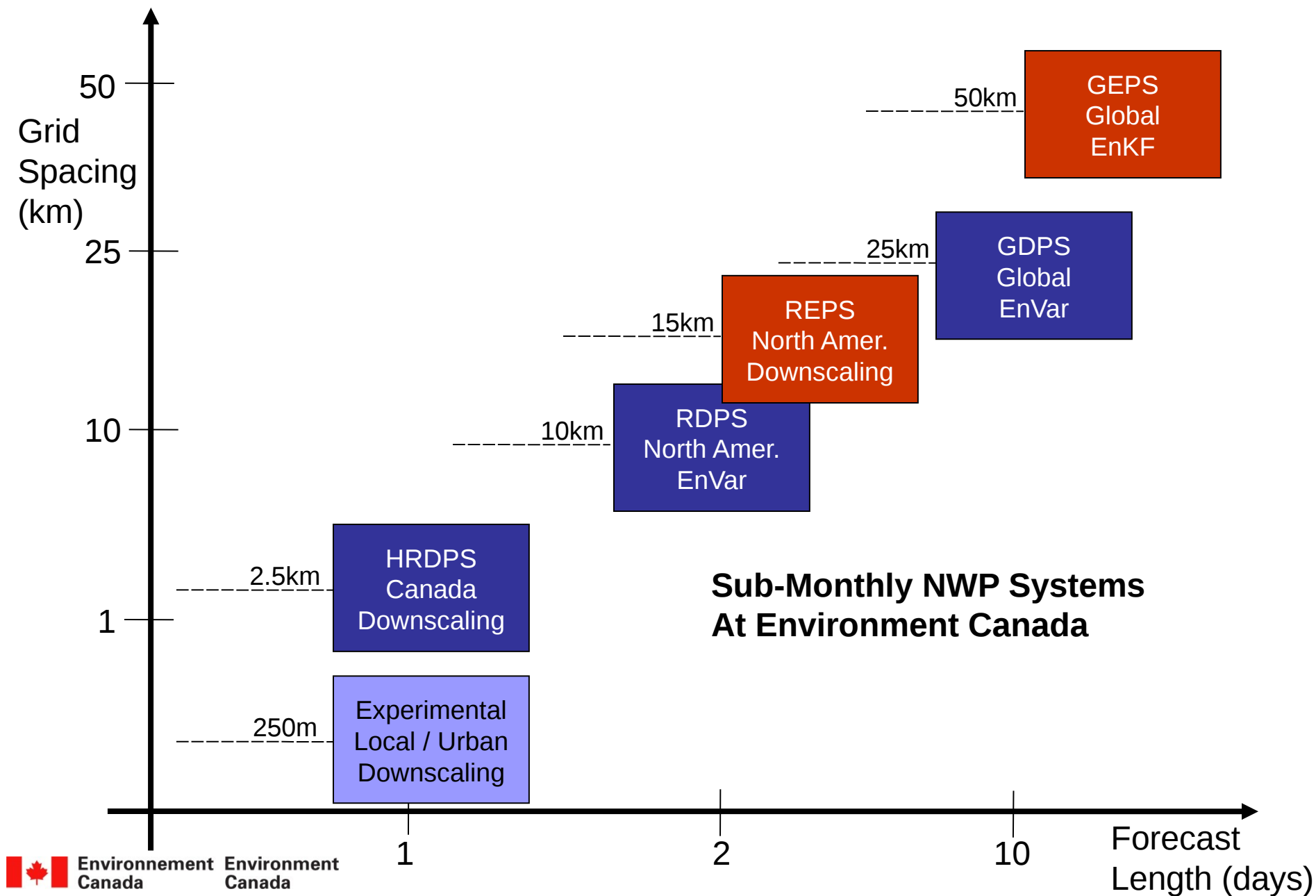
GSFC, NASA, 13 January 2015

Greater Emphasis on Surface Meteorology

Upper-air evaluation to compare Centers' performance

Different approach (more global) needed to determine true value of NWP systems

Emphasis on near-surface forecasts, felt by most NWP clients

Environnement Canada Environment Canada

Many Clients / Systems to Interface with

Grid Spacing (km)

- 50km — GEPS Global EnKF
- 25km — GDPS Global EnVar
- REPS North Amer. Downscaling
- 15km
- RDPS North Amer. EnVar
- 10km
- 2.5km — HRDPS Canada Downscaling
- 250m — Experimental Local / Urban Downscaling

50
25
10
1

Sub-Monthly NWP Systems At Environment Canada

Forecast Length (days)

1   2   10

Environnement Canada   Environment Canada

EC's Effort to Improve Land Surface

Characteristics and properties

Modeling – representation of processes

Data assimilation

Coupling with atmosphere

Environnement Environment
Canada Canada

The Surface Processor - Characteristics

DATABASES

GTOPO30
GMTED2010
SRTM-DEM-v4
ASTER-DEM
CDED2012
USGS-GLCC
MODIS-MCD12Q1
CCRS
GlobCover2.3
LCC2000-V
CanVec-9.0
OSM
NLCD2006
Census-StatCan2006
FAO
CANSIS
BNU Soil Dataset
JPL Soil Type
USDA STATSGO
HWSD
3D GlobVeg
NHD, NHN

GenPhysX / UrbanX

Vegetation fractions
Urban parameters
Water fraction
Soil texture
Drainage Density

MODIS ALBEDO CLIM.
MODIS NDVI CLIM.
BIOME-BGC CLIM.

PreX

Orographic parameters
Water fraction

OUT

IN

GEM or GEM-Surf

LEAF AREA INDEX
VEG. FRACTIONS
VEG. PARAMETERS
ALBEDOs
ROOT-ZONE DEPTH
SAND
CLAY
URBAN PARAMETERS

Environnement Environment
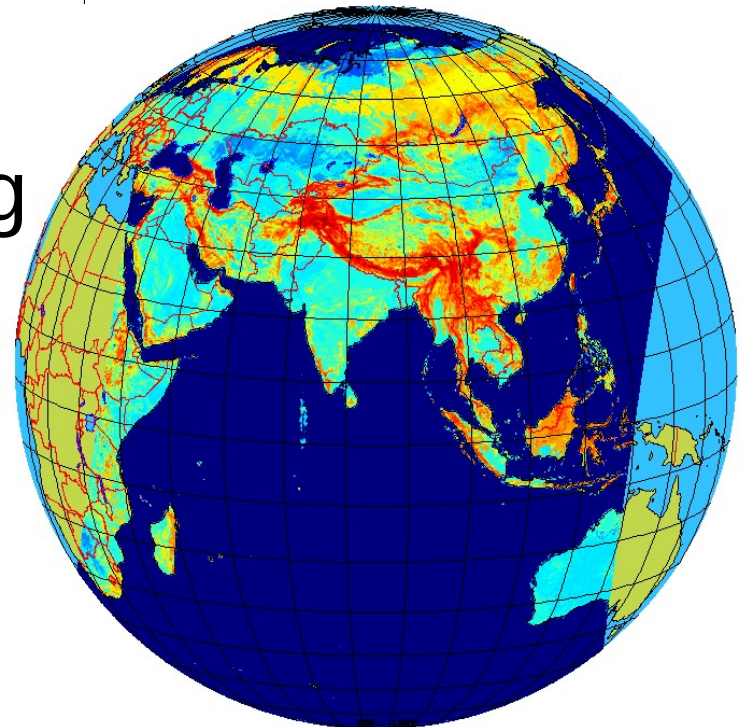Canada   Canada

(Vanh Souvanlasy)

Example: Global, 15 km, surface roughness

Yin
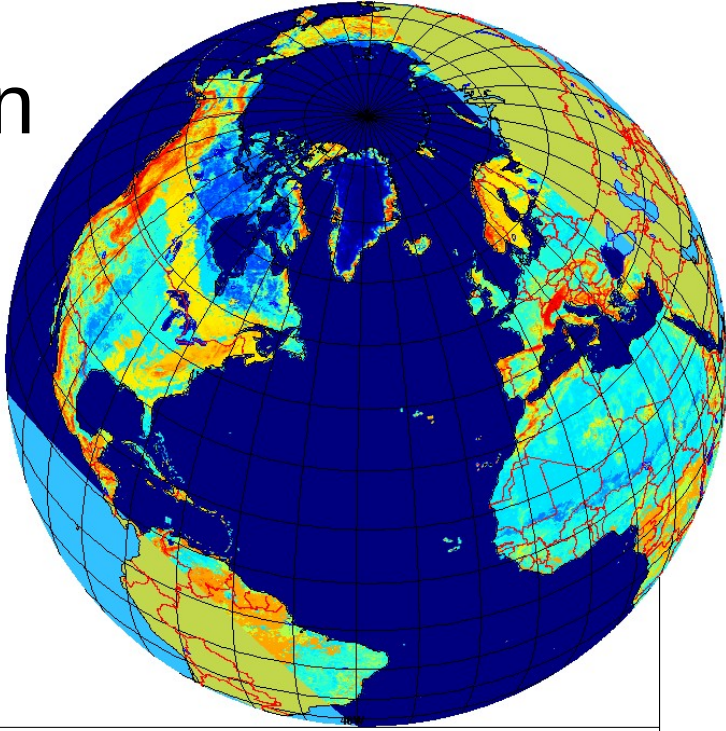
Yang

(Bernard Bilodeau)

Environnement Environment
Canada   Canada

Example: Regional, 2.5 km, Veg. Height

VCH

(m)

30
20
15
10
5
2
1
0

$$z_0 = \alpha h$$

Used for Z0 (local only), no orographic component
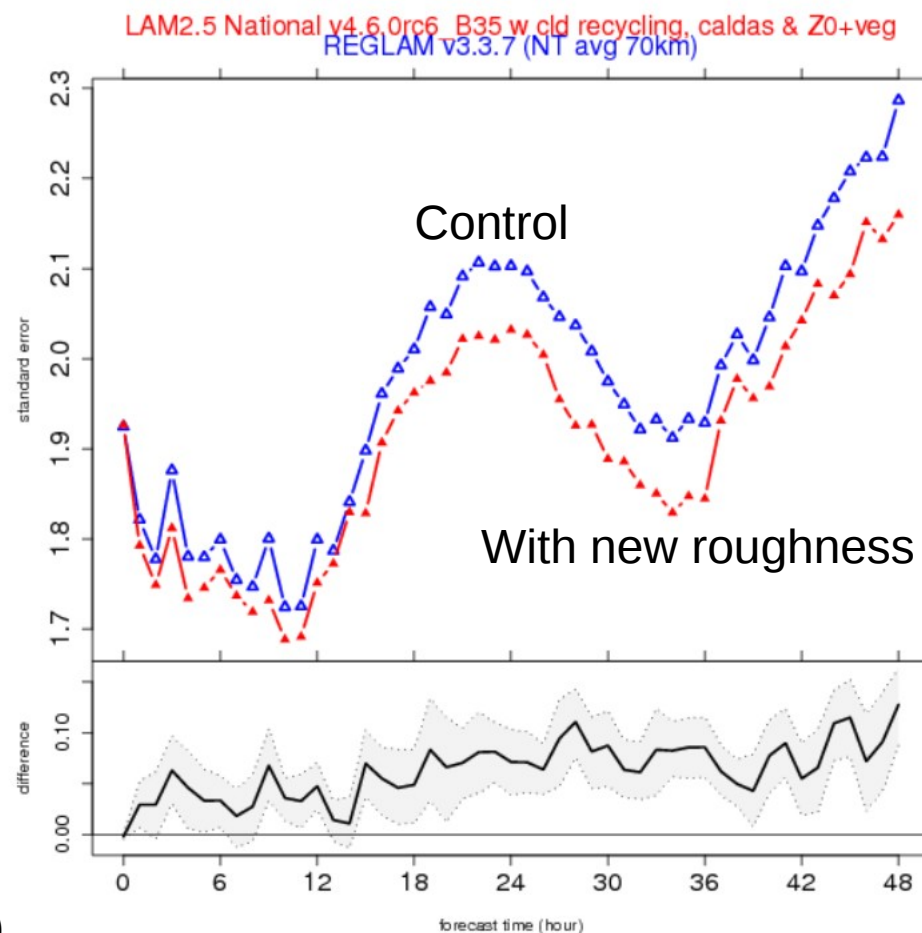
Simard et al. (2011) – JPL
From GLAS aboard ICESat
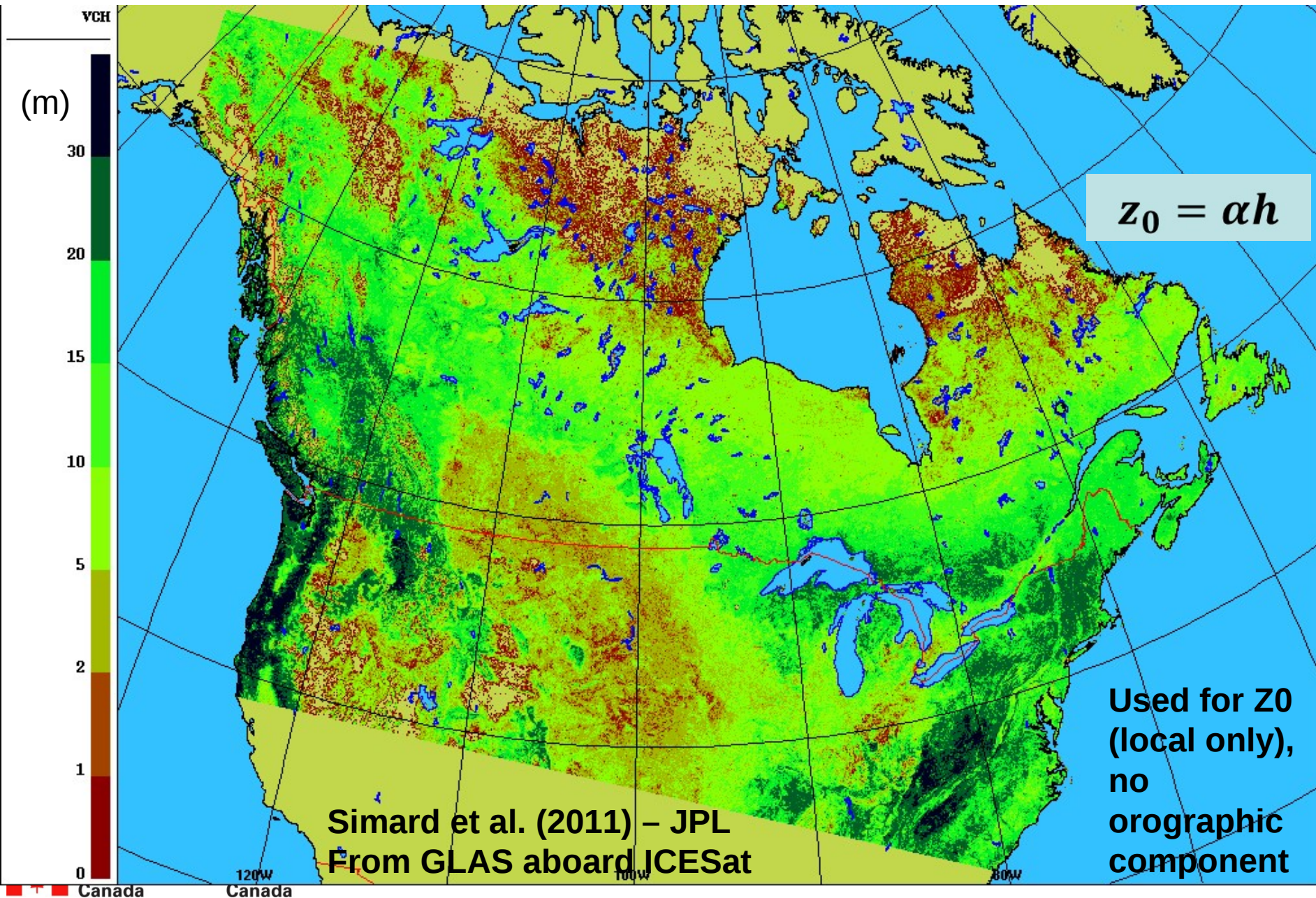
Impact on Near-Surface Winds

Pan Canadian 2.5-km system

10-m wind speed STDEs
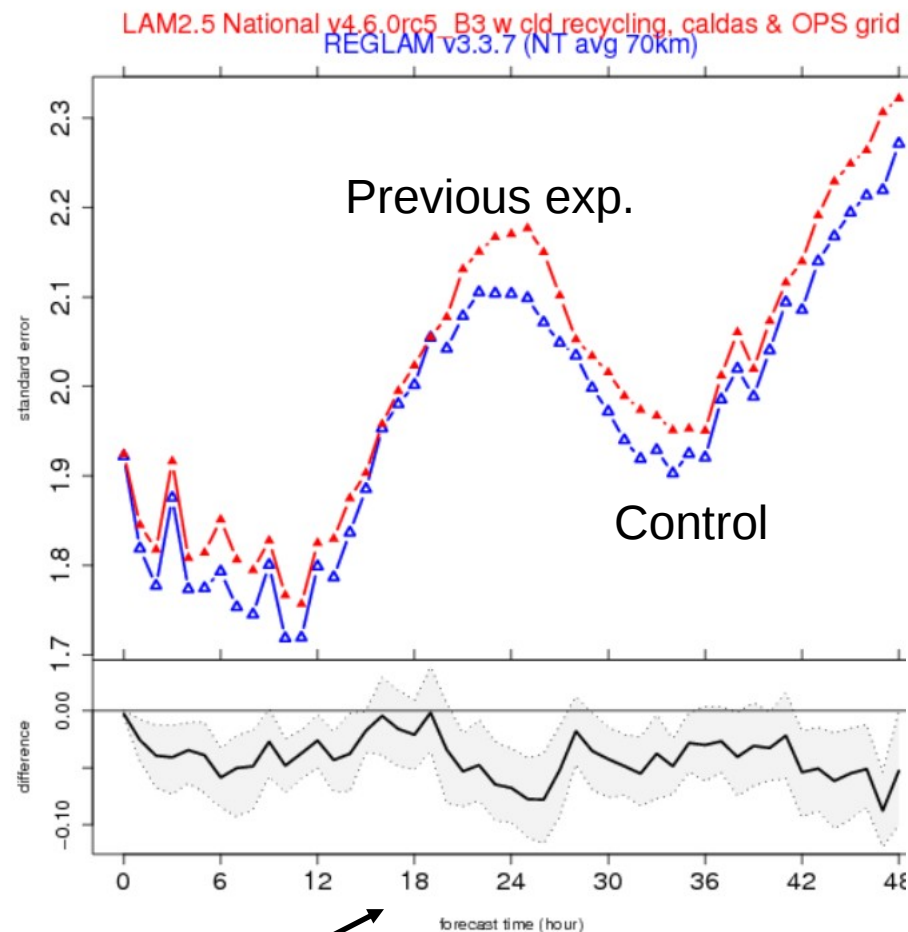
Reglam vs B3 (z0 from LUT)

20 summer cases (00 UTC)

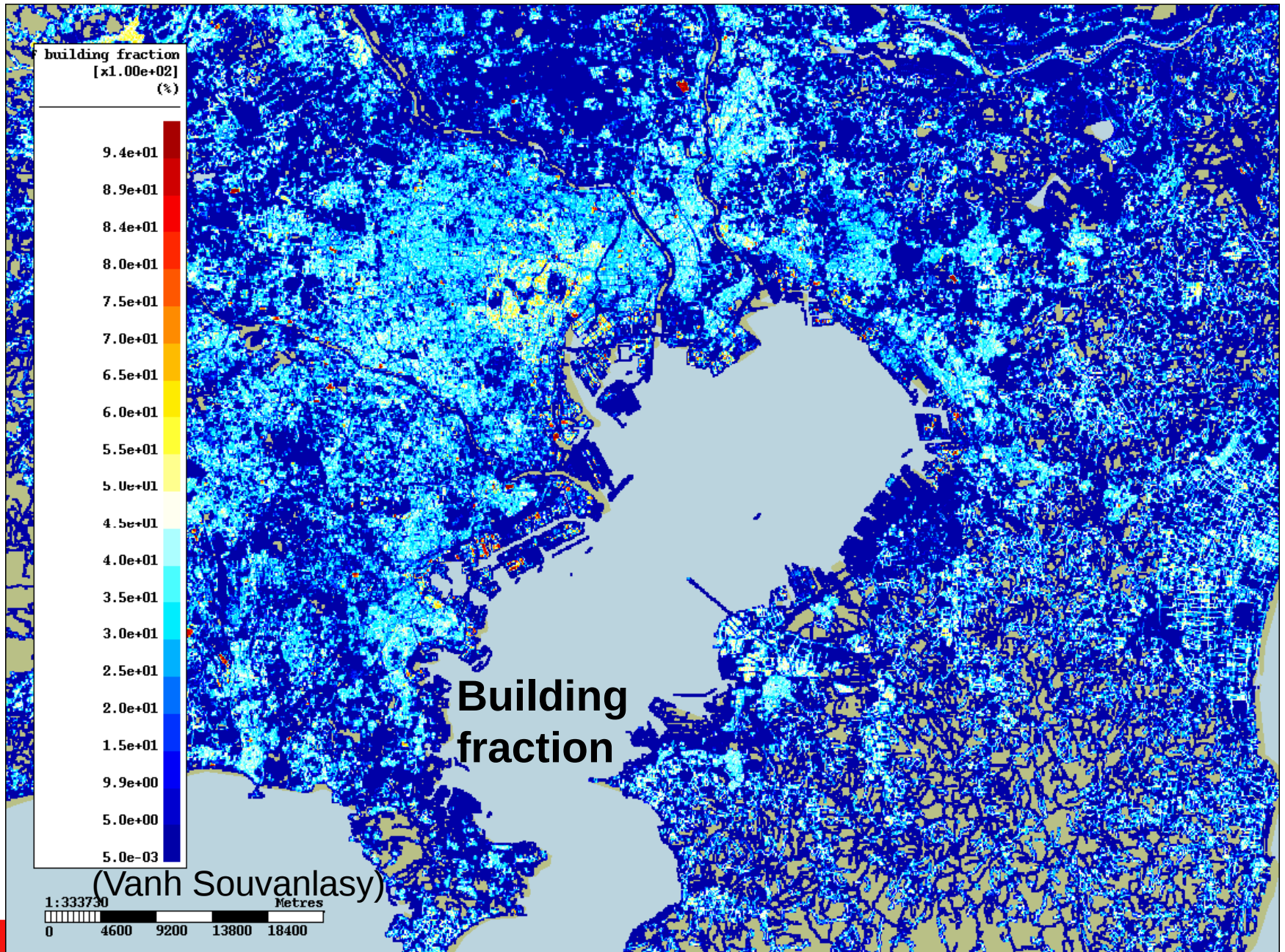Reglam vs B35 (z0 from JPL)

(Manon Faucher)

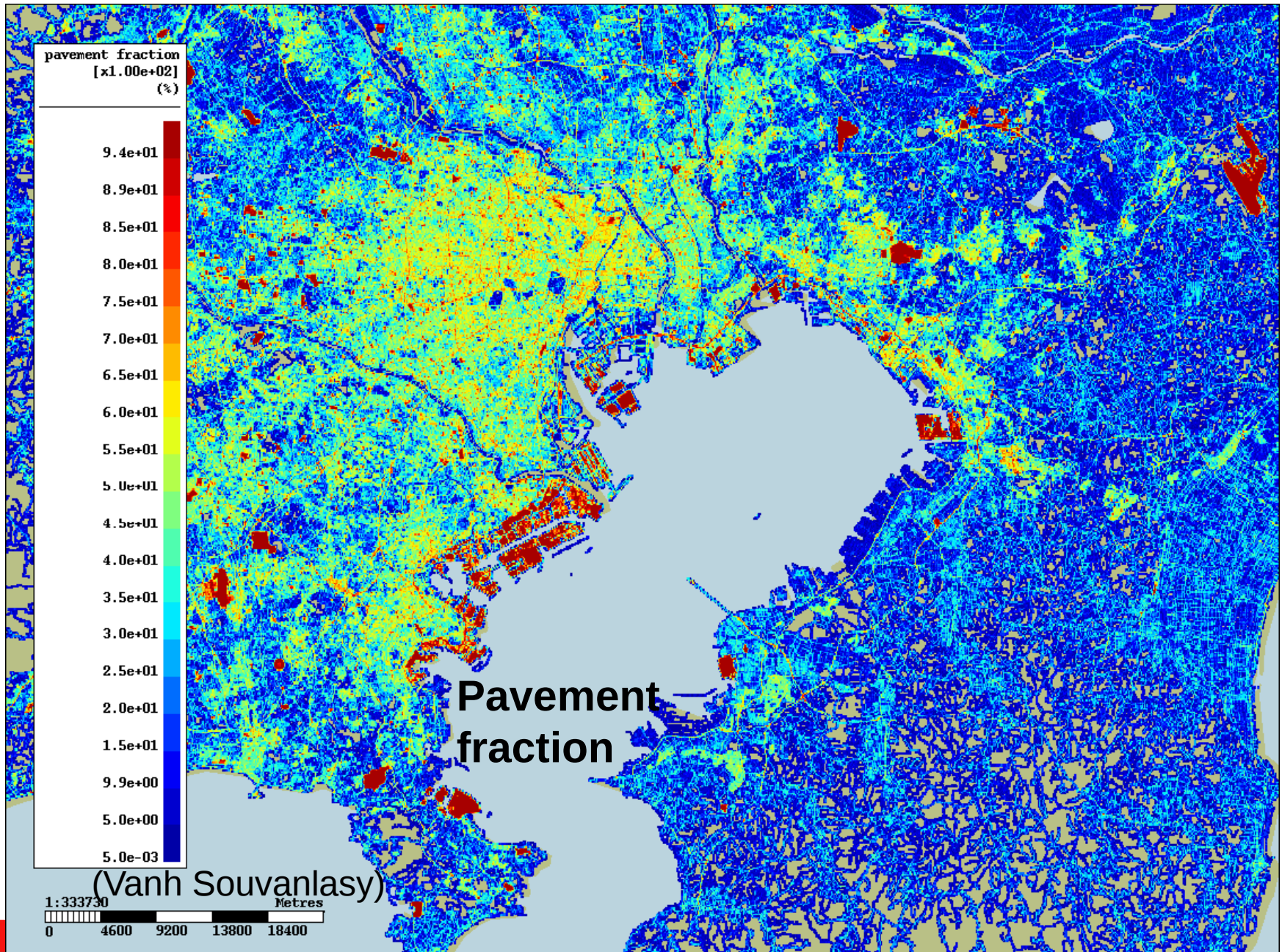Environnement Canada Environment Canada

Example: Local, 250 m, land cover

GREATER TORONTO AREA

Light grey: pavement fraction
Dark brown: building fraction

LAKE
ONTARIO

LAI (m²m⁻²)

Example: Local, 250 m, urban

building fraction
[x1.00e+02]
(%)

9.4e+01
8.9e+01
8.4e+01
8.0e+01
7.5e+01
7.0e+01
6.5e+01
6.0e+01
5.5e+01
5.0e+01
4.5e+01
4.0e+01
3.5e+01
3.0e+01
2.5e+01
2.0e+01
1.5e+01
9.9e+00
5.0e+00
5.0e-03

Building fraction

(Vanh Souvanlasy)

1:333730   Metres

0   4600   9200   13800   18400

Example: Local, 250 m, urban

pavement fraction
[x1.00e+02]
(%)

9.4e+01
8.9e+01
8.5e+01
8.0e+01
7.5e+01
7.0e+01
6.5e+01
6.0e+01
5.5e+01
5.0e+01
4.5e+01
4.0e+01
3.5e+01
3.0e+01
2.5e+01
2.0e+01
1.5e+01
9.9e+00
5.0e+00
5.0e-03

Pavement fraction

(Vanh Souvanlasy)

1:333730   Metres

0   4600   9200   13800   18400

Urban Areas in North America
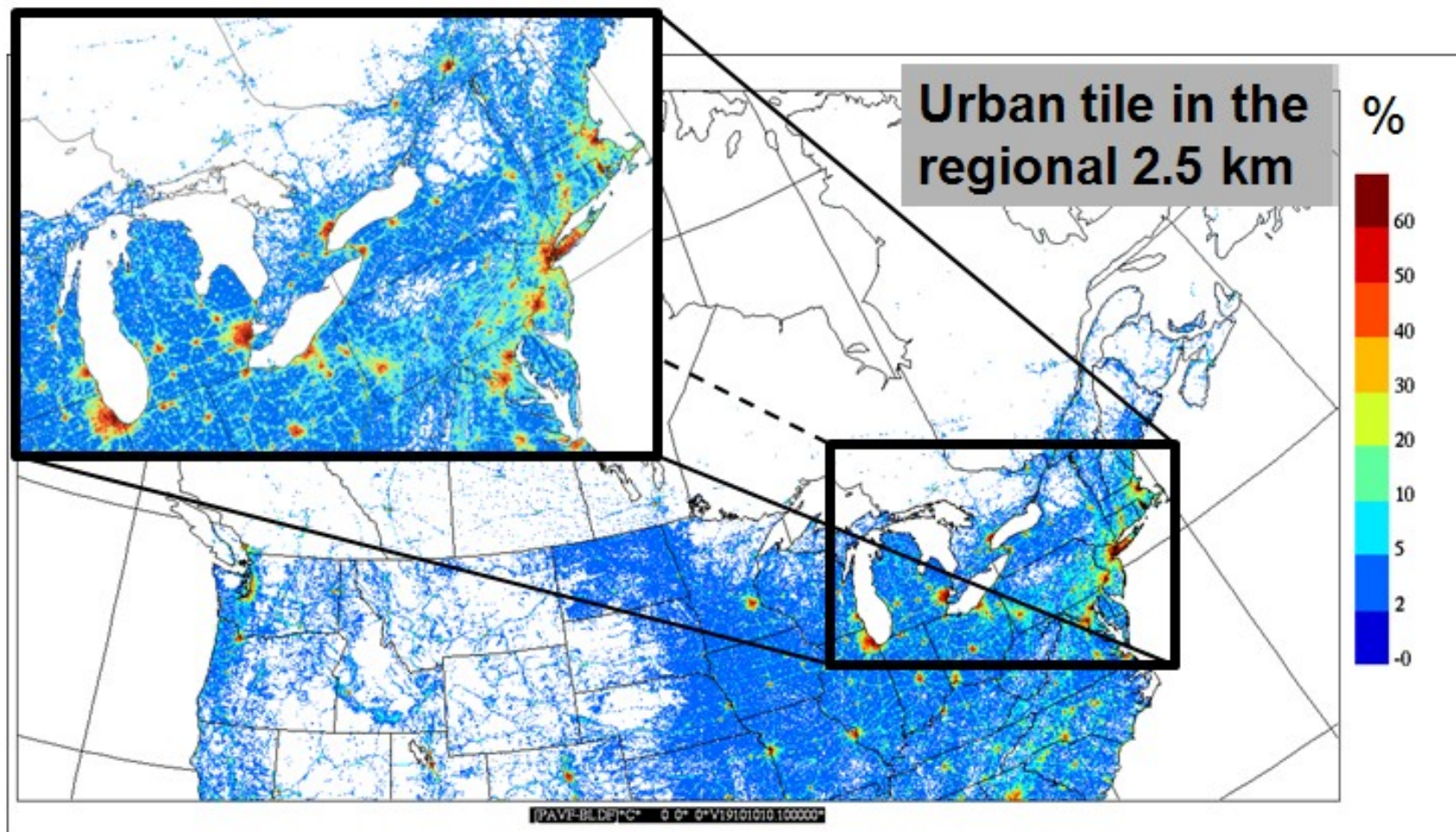
(Vanh Souvanlasy, Sylvie Leroyer)

Land Surface Models
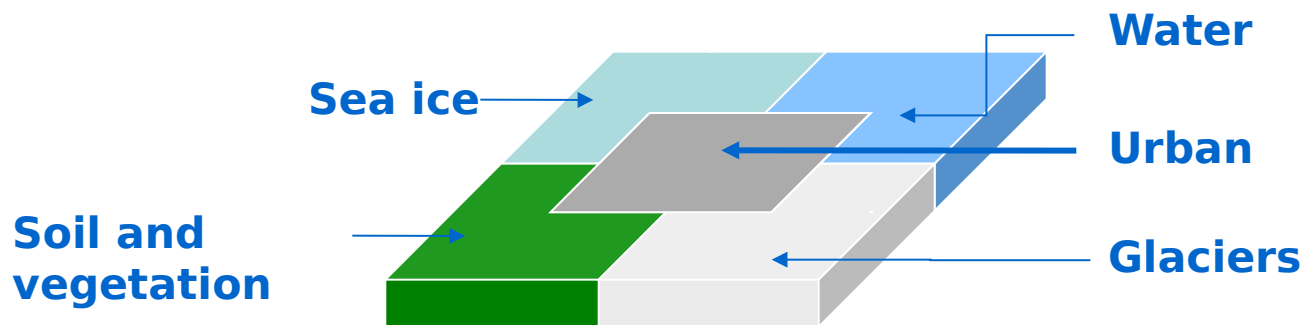
Natural Land	ISBA, SVS, CLASS
Water	Simple scheme with constant surface temperature (NEMO for 3D lakes + 1D lake model)
Urban	TEB
Glaciers	Force-restore scheme (with snow), module from CLASS
Sea ice	3-layer model with snow on top (LIM2 or CICE)
Snow	Simple schemes over glaciers and sea ice; one layer model in ISBA and SVS, slightly more complex in TEB and CLASS

The Soil, Vegetation, and Snow Scheme

Multiple energy and water budgets (new subgrid-scale tiling)

Multi-layer model for soil moisture
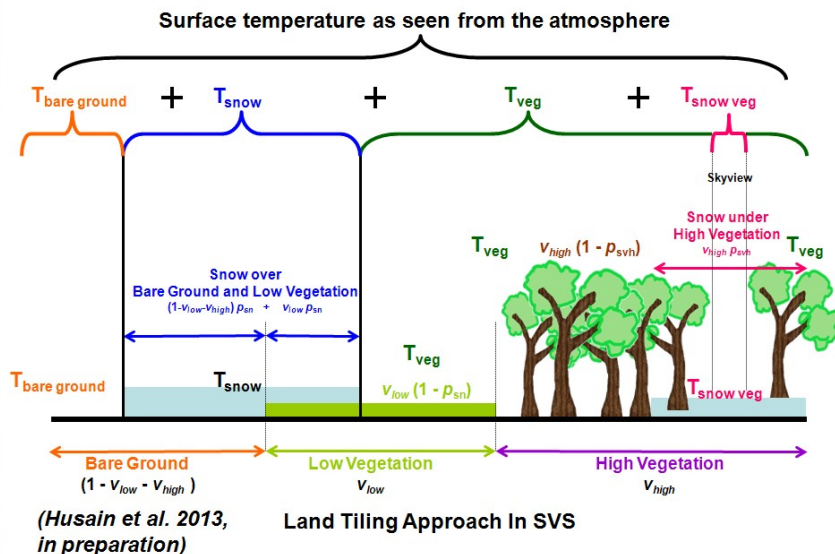
New snow pack under the vegetation

Root density function depending on vegetation type

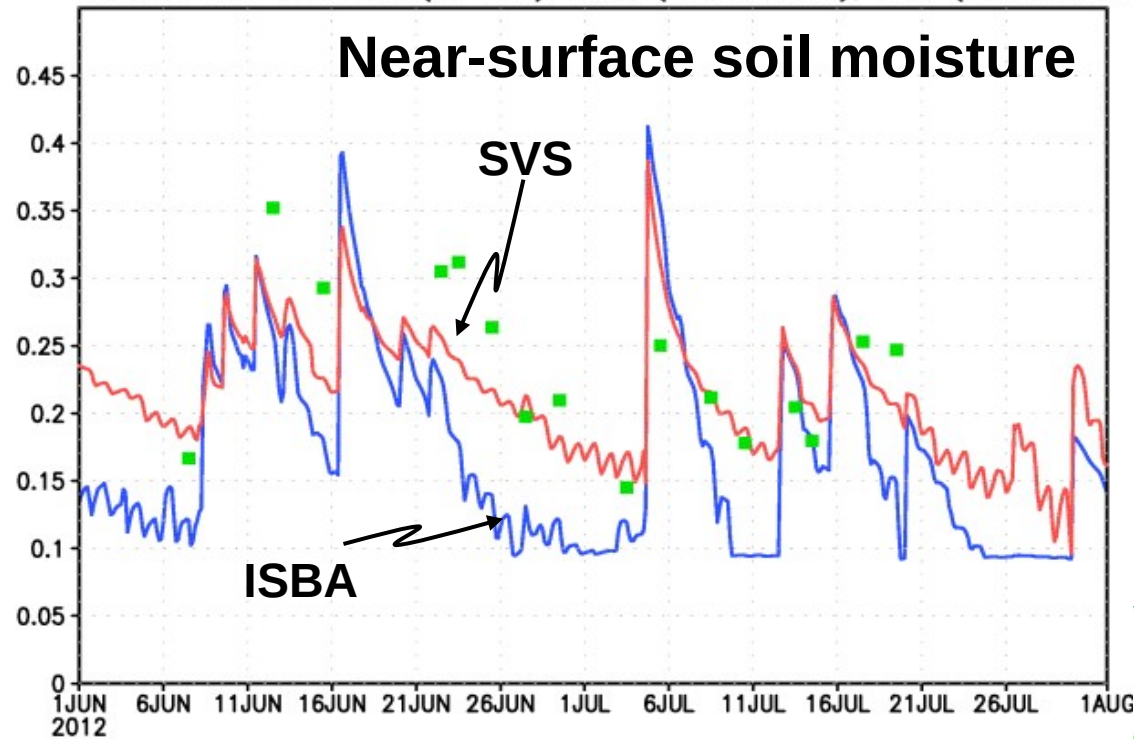*Changes to vegetation thermal coefficient, albedo, and emissivity*

Stomatal resistance from photosynthesis scheme
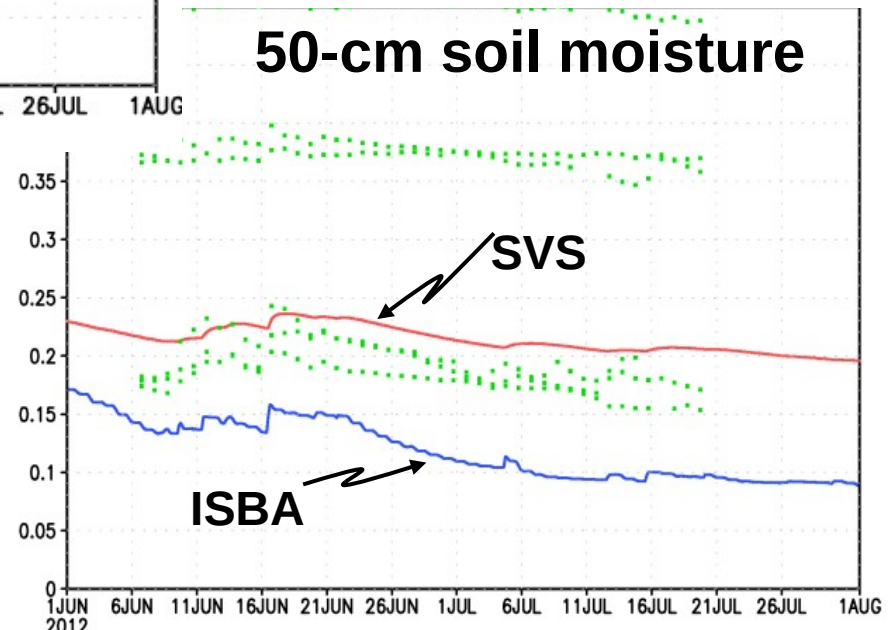
Not changed: still a single canopy layer scheme

The SOIL and VEGETATION SIMULATOR (SVS): MULTI BUDGET / TILING

Land Tiling Approach In SVS
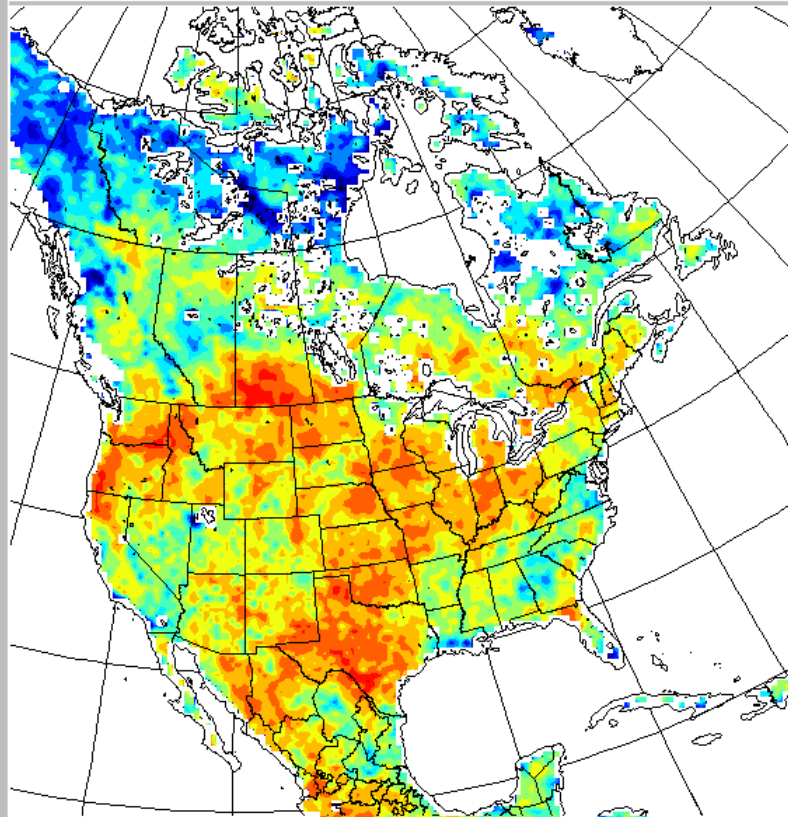
(Husain et al. 2013, in preparation)

HYDROLOGY
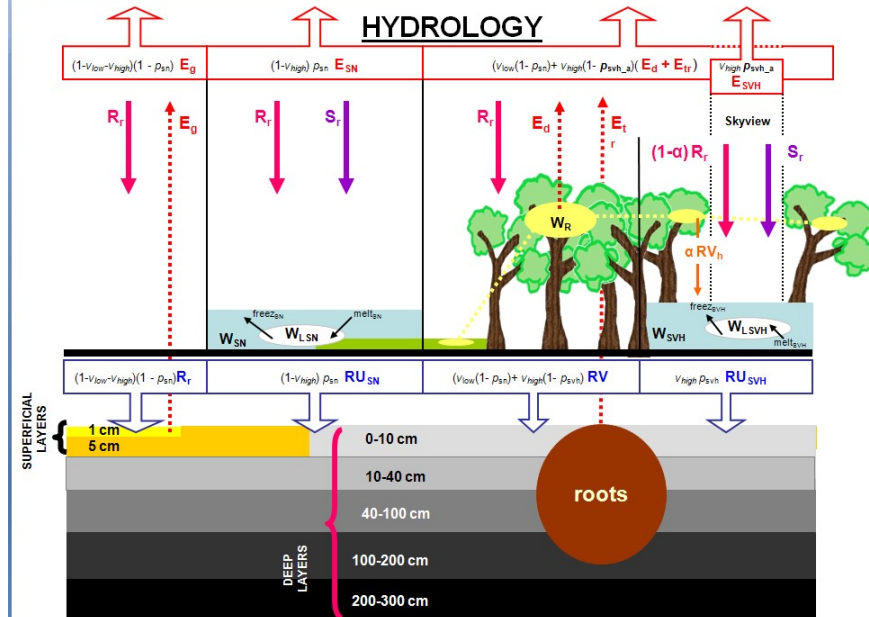
SVS: Impact on Soil Moisture

Near-surface soil moisture

SVS

ISBA

**SMAPVEX12
Southern Manitoba
June 2012**

50-cm soil moisture

SVS

ISBA

Environnement Environment
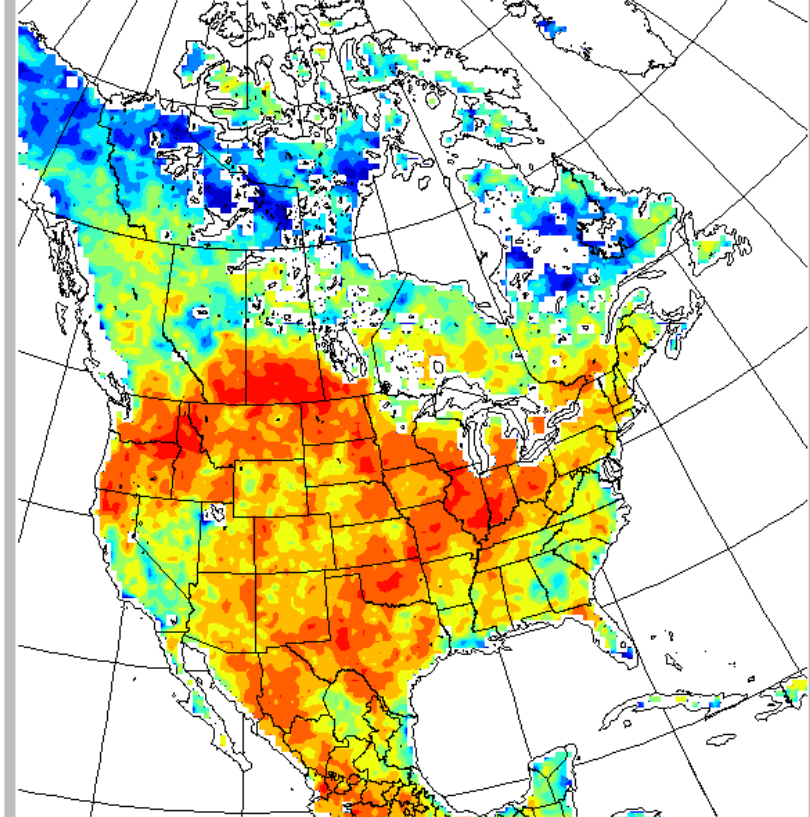Canada   Canada

(Shunli Zhang)

SVS: Impact on L-Band Forward Modeling

Horizontal Polarization : 40° Incidence Angle
May – September 2012

ISBA
CORRELATION MEAN: 0.44

SVS
CORRELATION MEAN: 0.46

(Shunli Zhang, Marco Carrera)

Environnement Environment
Canada Canada

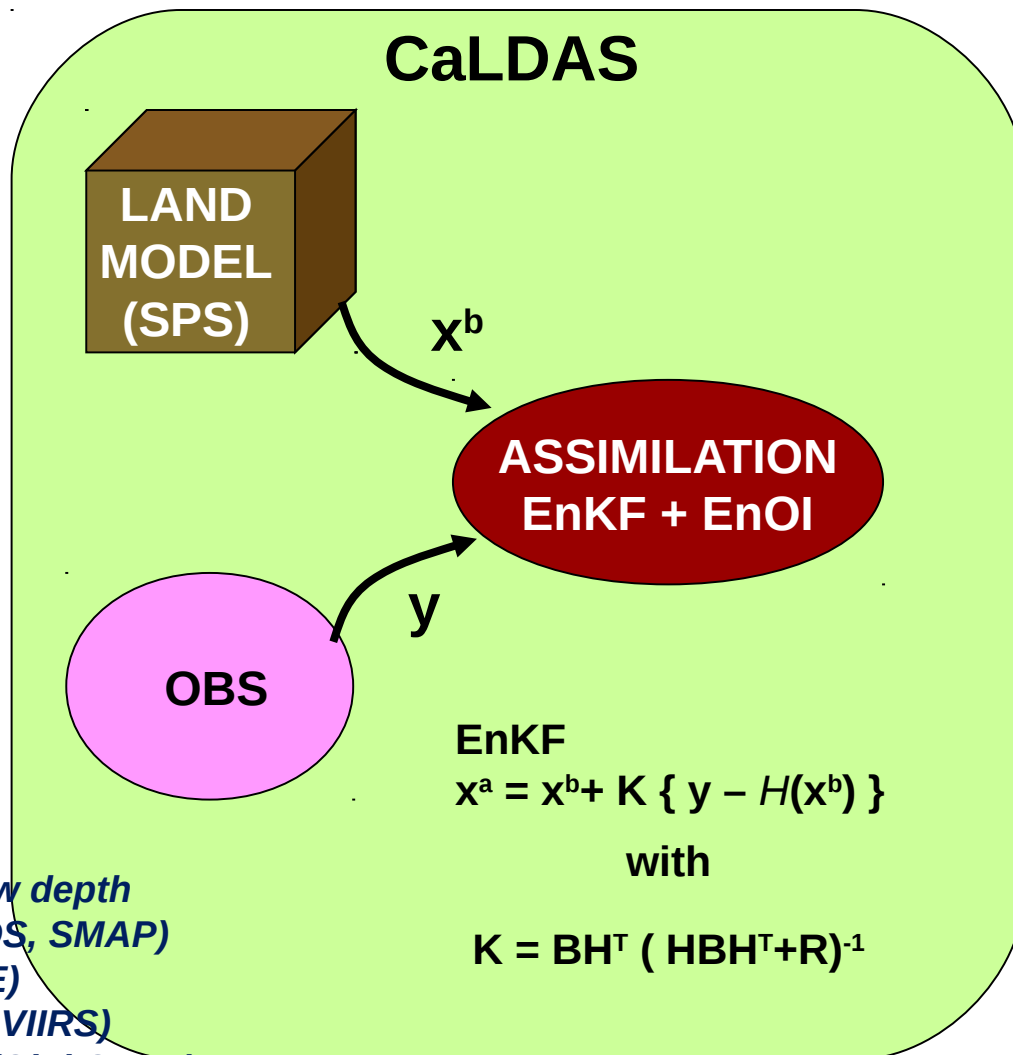# EC's Land Data Assimilation Effort

IN

Ancillary land surface data

Orography, vegetation, soils, water fraction, ...

Atmospheric forcing

T, q, U, V, Pr, SW, LW

Observations

Screen-level (T, Td)
Surface stations snow depth
L-band passive (SMOS, SMAP)
MW passive (AMSR-E)
*Optical / IR (MODIS, VIIRS)
Combined products (GlobSnow)

CaLDAS

LAND MODEL (SPS)

x^b

ASSIMILATION EnKF + EnOI

y

OBS

EnKF
$x^a = x^b + K \{ y - H(x^b) \}$

with

$K = BH^T (HBH^T + R)^{-1}$

OUT

Analyses of…

Surface Temperature

Soil moisture

Snow depth or SWE

Vegetation*

Environment Canada Environnement Canada

*) not done yet…

CSA ASC

First Implementations of CaLDAS

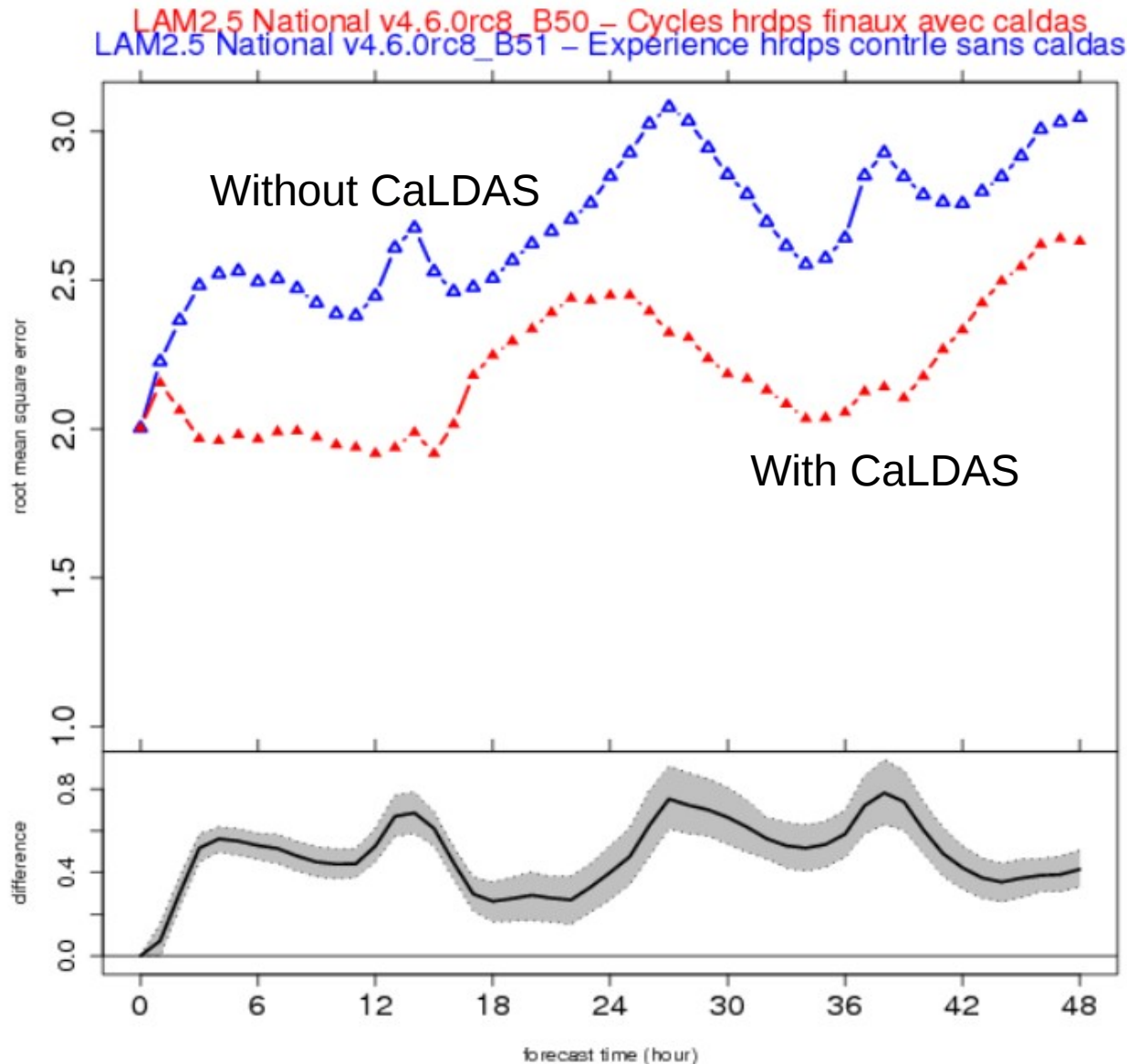| OBS	Method	Control variables
Screen-level air temperature and dew point temperature	EnKF	Soil moisture and surface temperature
Surface obs of snow depth	EnOI	Snow water equivalent

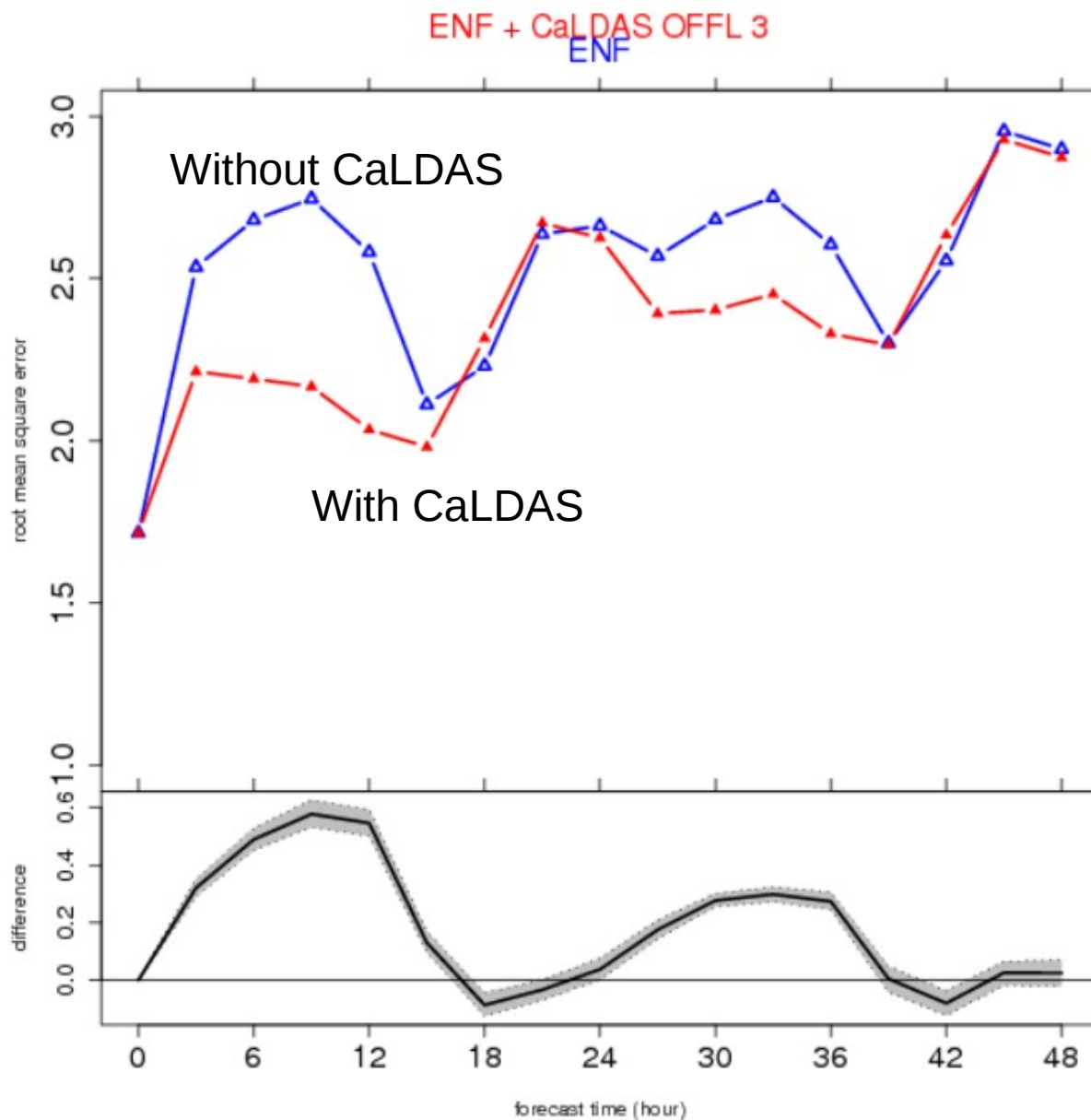**Regional** (Canada + part of USA), 2.5 km
Global, Yin-Yang grid, 25 km

Both systems implemented in Fall 2014 at MSC-Operations

CaLDAS: Impact on HRDPS (2.5 km)
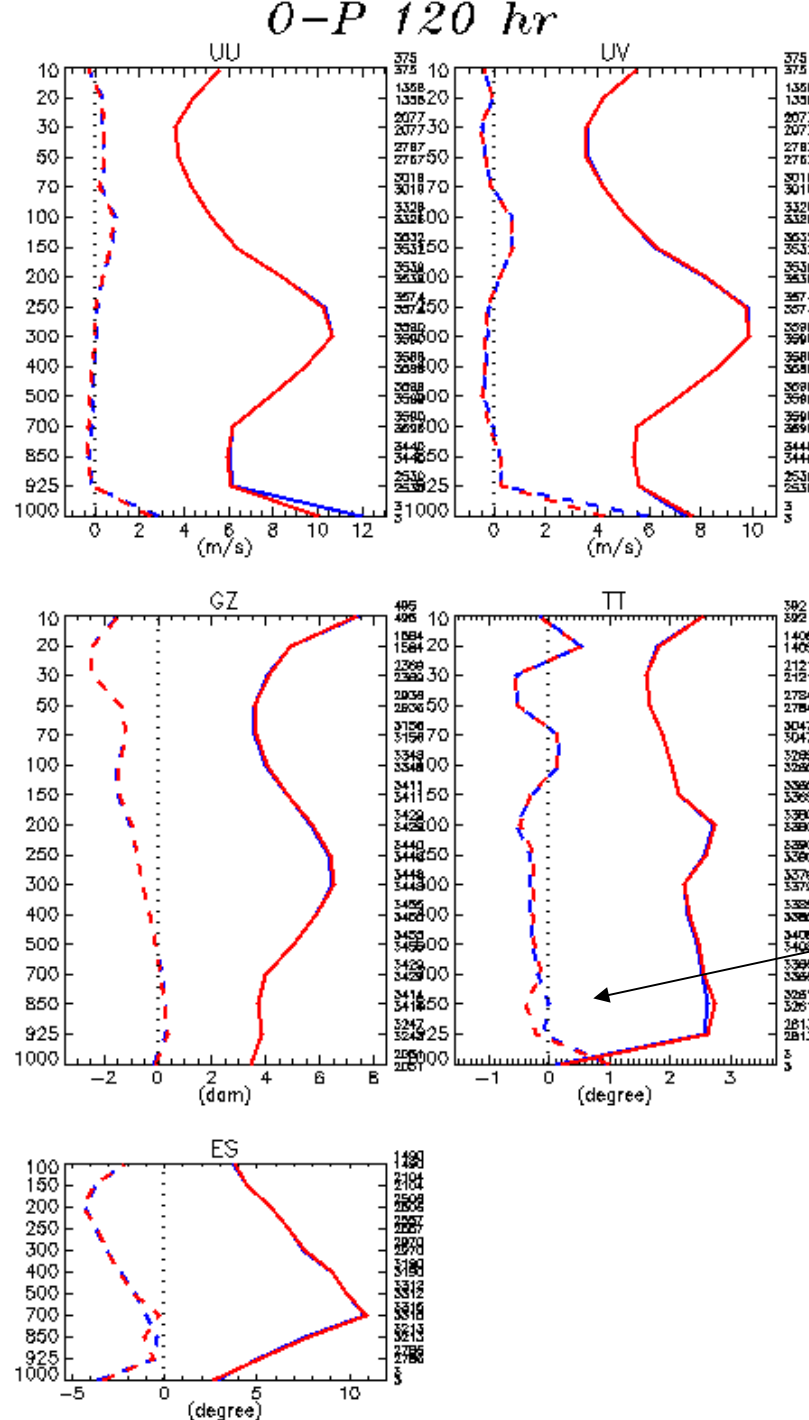

RMSE, Td_2m
20 summer cases
Canada

(Manon Faucher)

CaLDAS: Impact on RDPS (10 km)

RMSE, TT_2m
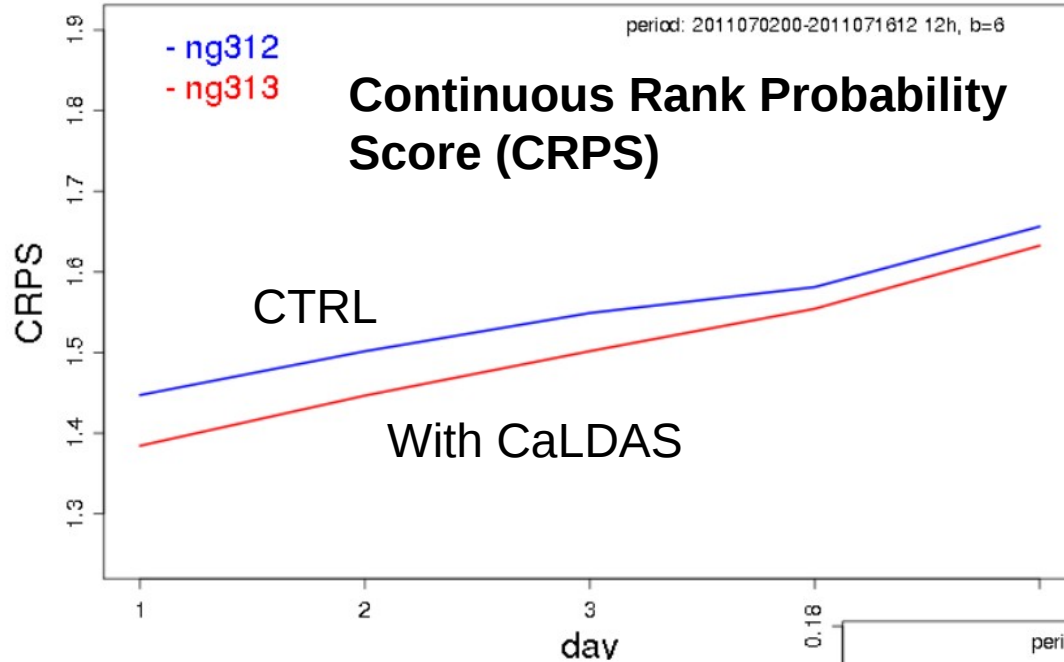20 summer cases
USA

(Jean-Francois Caron)

CaLDAS: Impact on GDPS (25 km)

Upper-air evaluation
Against radiosondes
Southern Hemisphere
June-July-August
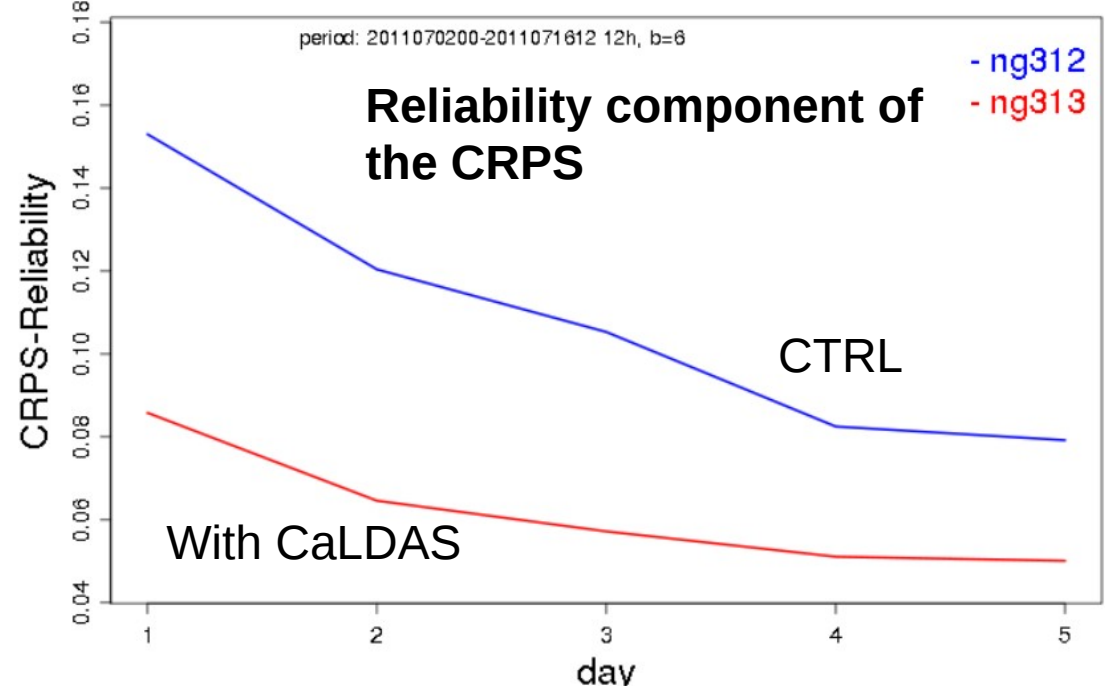About 100 cases
5-day forecasts

(Bernard Bilodeau)

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Canada Canada

CaLDAS: Impact on GEPS (Ensemble)

Continuous Rank Probability Score (CRPS)

CTRL

With CaLDAS

Over North America

2-m temperature

Reliability component of the CRPS

CTRL

With CaLDAS

(Normand Gagnon)

Environnement Environment
Canada   Canada

Assimilation of L-Band Data in CaLDAS

SMOS NRT-light L-band Tbs (40 km, multi-angles)

QA/QC: exclusive alias-free zone, simple tests

Rescaling of Tbs based on CDF matching
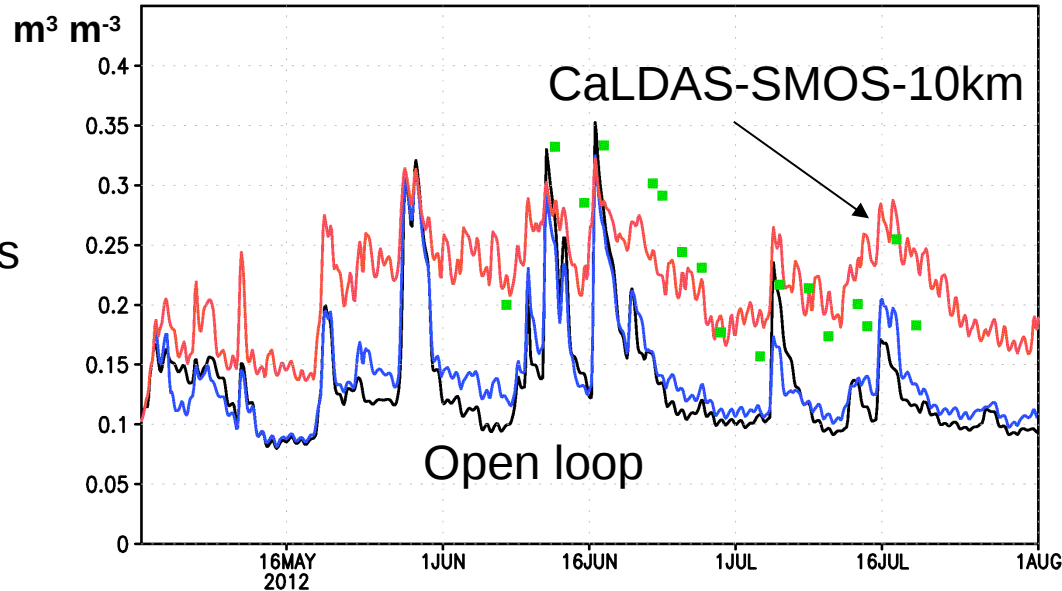
Tb obs. error chosen as 5 K (homogeneous)

EnKF: 24 members, 10 km analyses, wg and w2
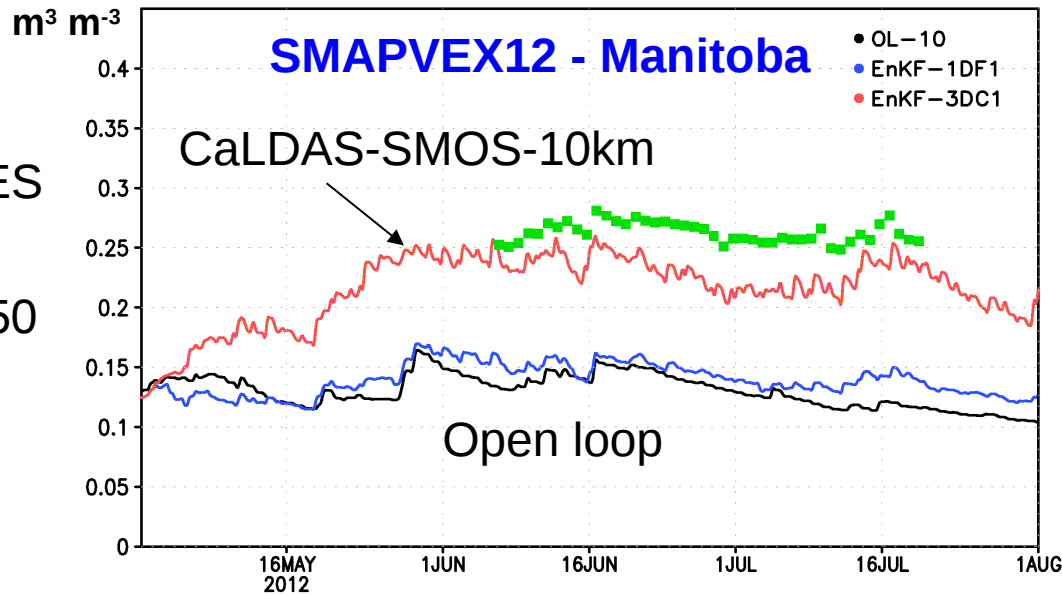
EnKF: 3h frequency, CMEM forward model

Tested in synthethic mode and over SMAPVEX12

Impact of L-Band Data on Soil Moisture

Mean of sampled fields

(6 cm)

CaLDAS-SMOS-10km

Open loop

AAFC SAGES mean

(5, 20 and 50 cm).

SMAPVEX12 - Manitoba

CaLDAS-SMOS-10km

Open loop

- OL−10
- EnKF−1DF1
- EnKF−3DC1

(Marco Carrera)

Environnement Environment
Canada Canada

Towards a More Complete CaLDAS

Starting point: CaLDAS-screen 2.5km (OP)

Addition of the SMOS component (combination with screen-level obs, simultaneous or sequential)

Addition of the SVS surface scheme for the first guess

To be tested first in regional 10-km mode (NAM)

To be extended afterward to Canada 2.5-km (first) and to global 15 km (second)
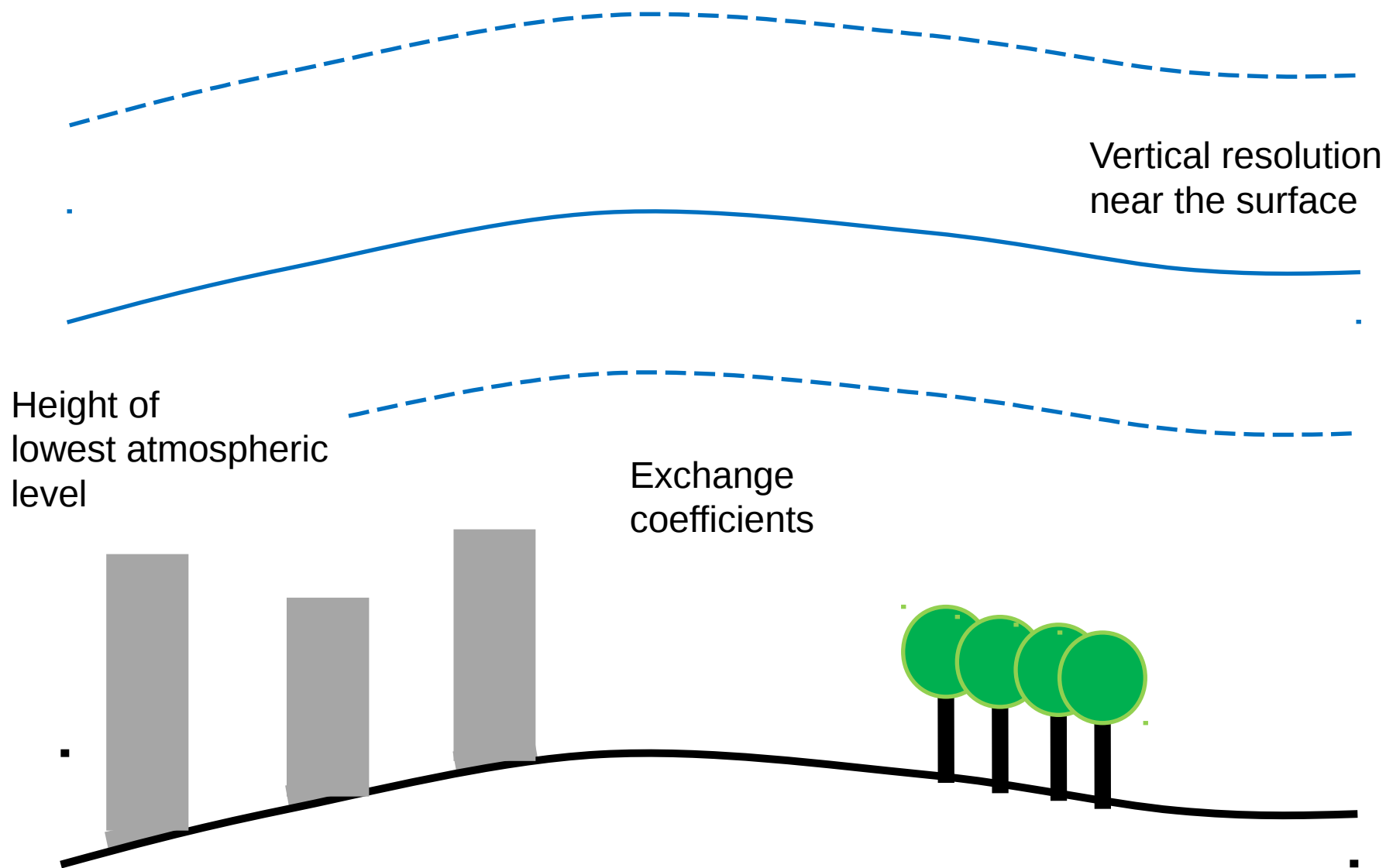
Ready for SMAP... (Passive at Least...)

http://meteocentre.com/plus/
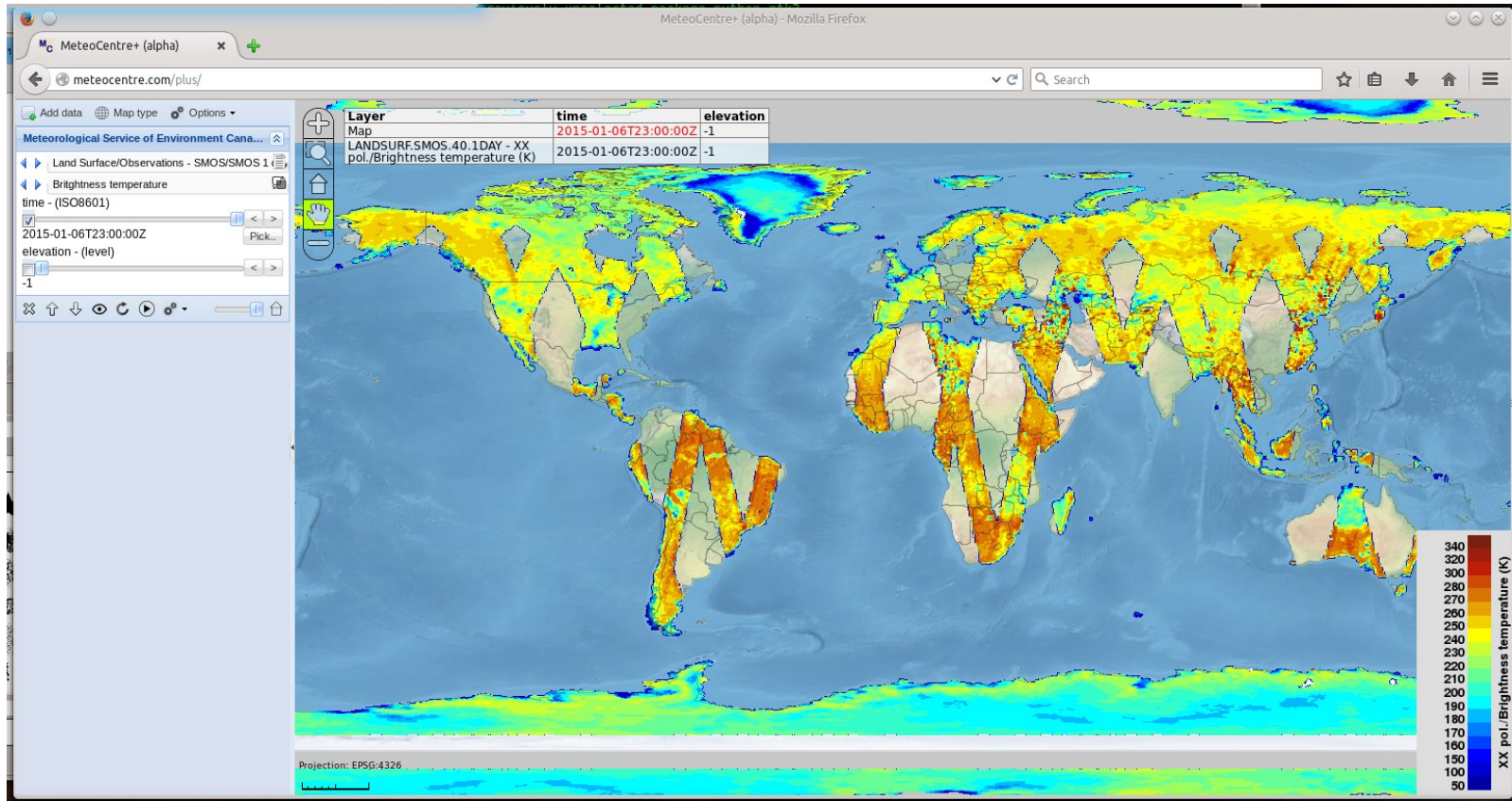
Current monitoring of SMOS observation
Same apparatus will be used for SMAP
Test with data as soon as possible

Environnement Canada Environment Canada
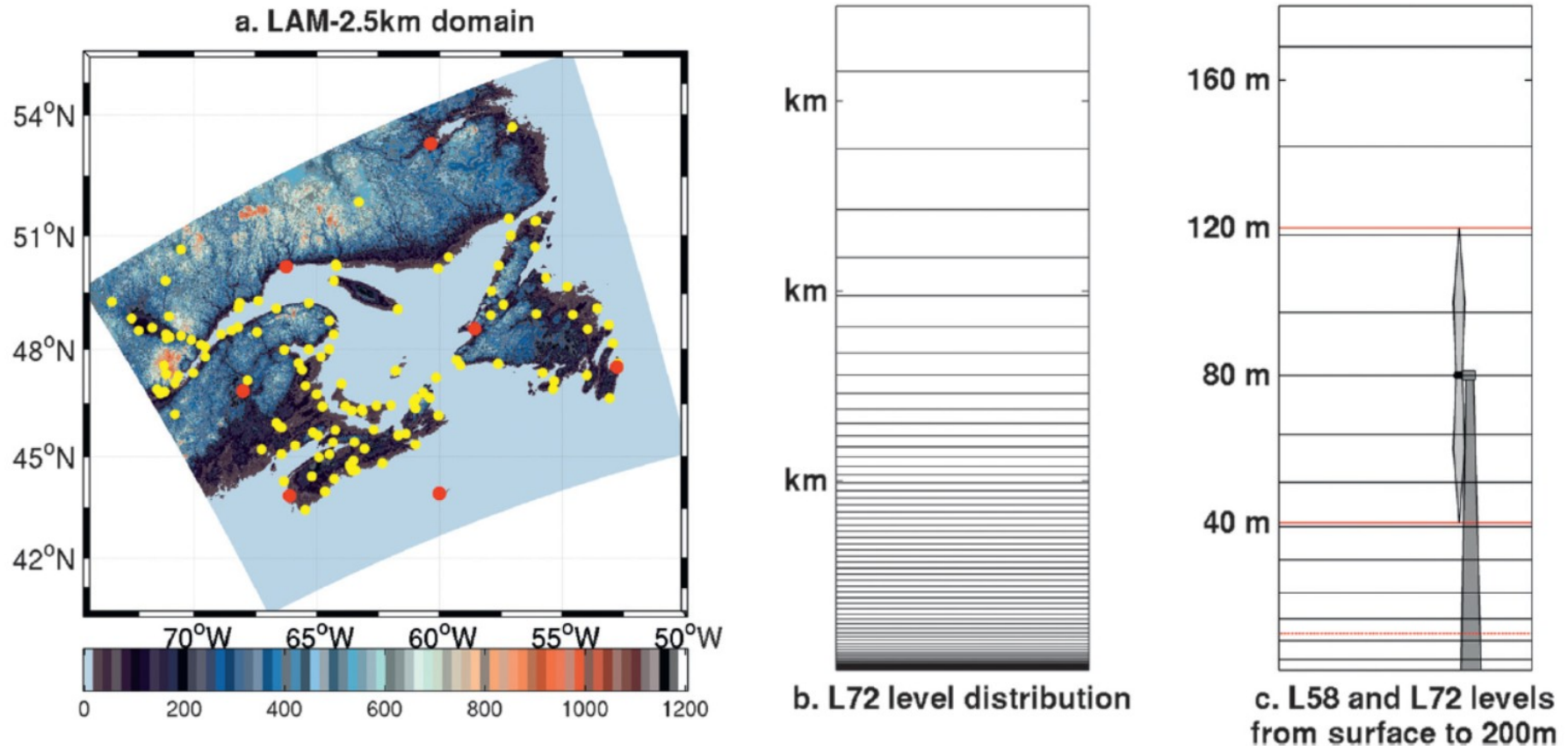
Traditional Land-Atmosphere Coupling

Vertical resolution near the surface

Height of lowest atmospheric level

Exchange coefficients

EC R&D on Land – Atmosphere Coupling

Lower atmospheric levels near the surface (as close as 1.5m for thermodynamic level)
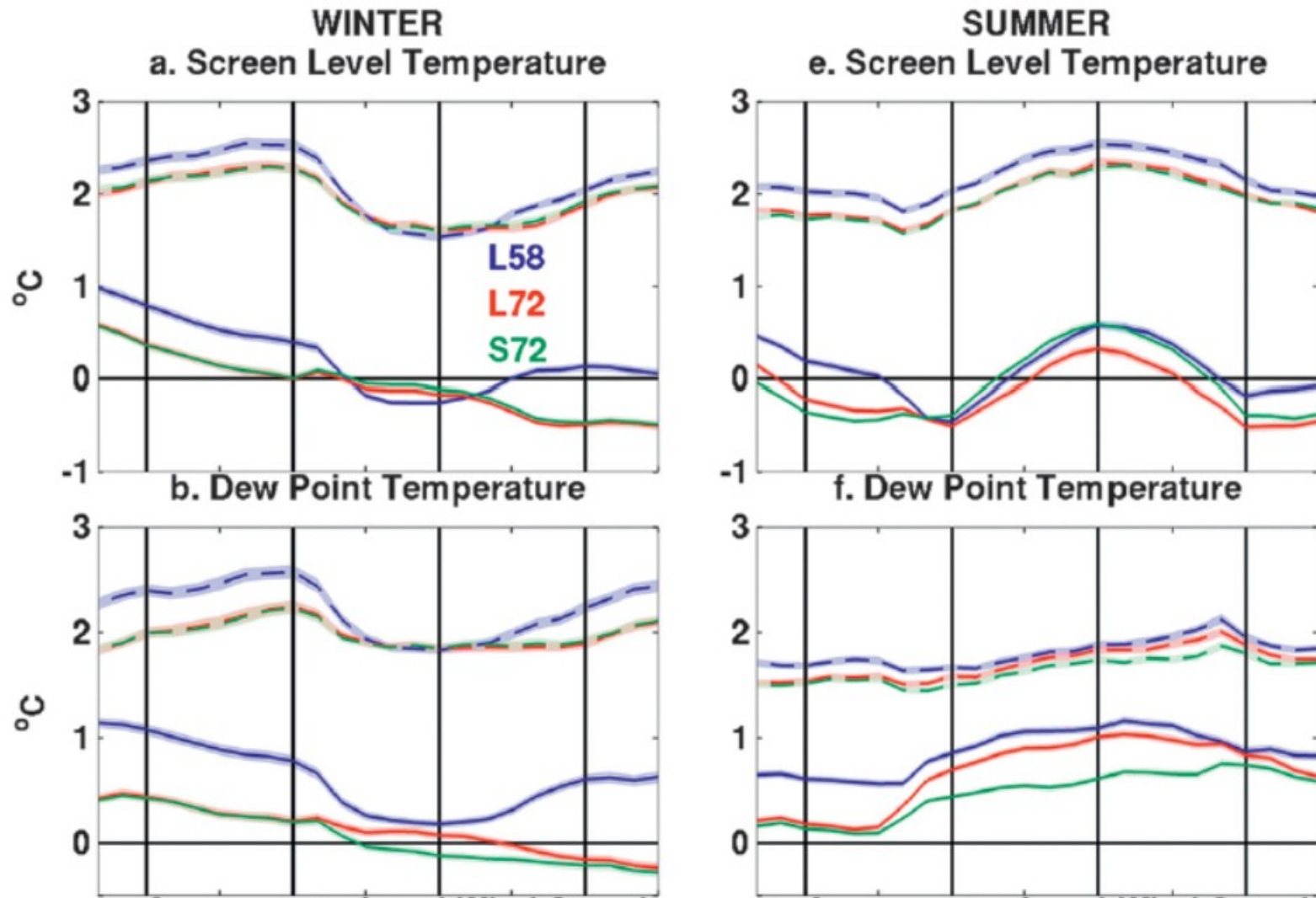
Changes to the nature of the land-atmosphere interactions with atmospheric levels intersecting with vegetation and urban canopies.

Two-way coupling: low-res atmospheric model with high-res surface system
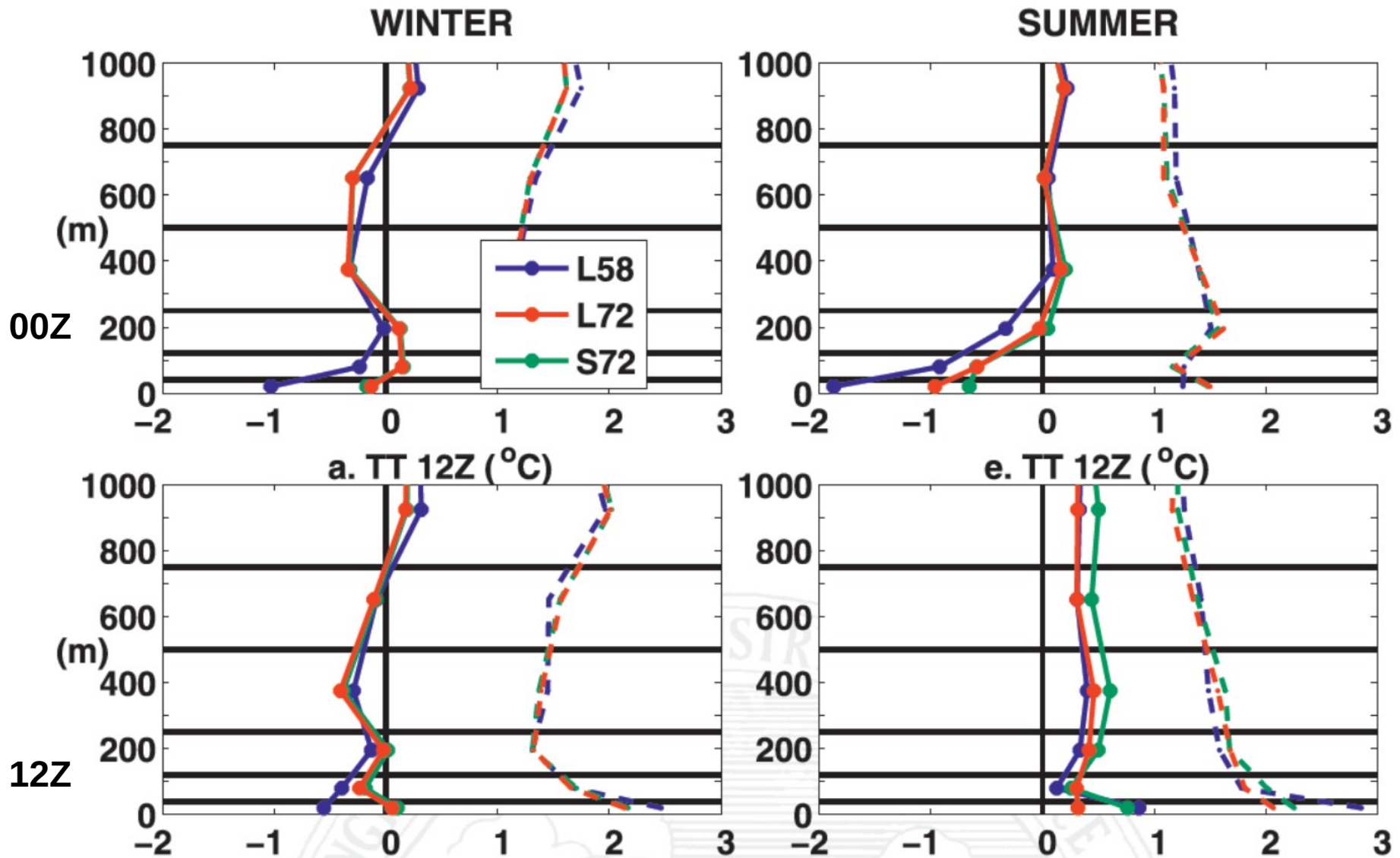
Increased Vertical Resolution near Surface

a. LAM-2.5km domain

b. L72 level distribution

c. L58 and L72 levels from surface to 200m

Figure 1 in Bernier and Belair, 2012, J. Appl. Meteorol.

Impact on Screen-Level Variables

WINTER

a. Screen Level Temperature

b. Dew Point Temperature

SUMMER

e. Screen Level Temperature

f. Dew Point Temperature

L58
L72
S72

15 winter cases, and 15 summer cases

Figure 3 in Bernier and Belair, 2012, J. Appl. Meteorol.

Impact on Near-Surface Profiles

15 winter cases, and 15 summer cases

Figure 4 in Bernier and Belair, 2012, J. Appl. Meteorol.

Vertical Aspect of Coupling

SINGLE GEM (ATMOSPHERE) GRID AREA (LOW RES)

INCREASED VERTICAL RESOLUTION

*SPATIAL AVERAGE of **IMPLICIT** LOWER BC for VERT. DIFFUSION (to be applied over atmospheric level just above canopy / soil water / ice)*

SPATIAL AVG of TENDENCIES for EACH INTERSECTING LEVEL

WATER

LAND / VEG (ISBA / SVS)

URBAN (TEB)

MULTIPLE SURFACE GRID AREAS (HIGH RES)

Environnement Canada   Environment Canada

Coupling Urban Canopy with Atmosphere
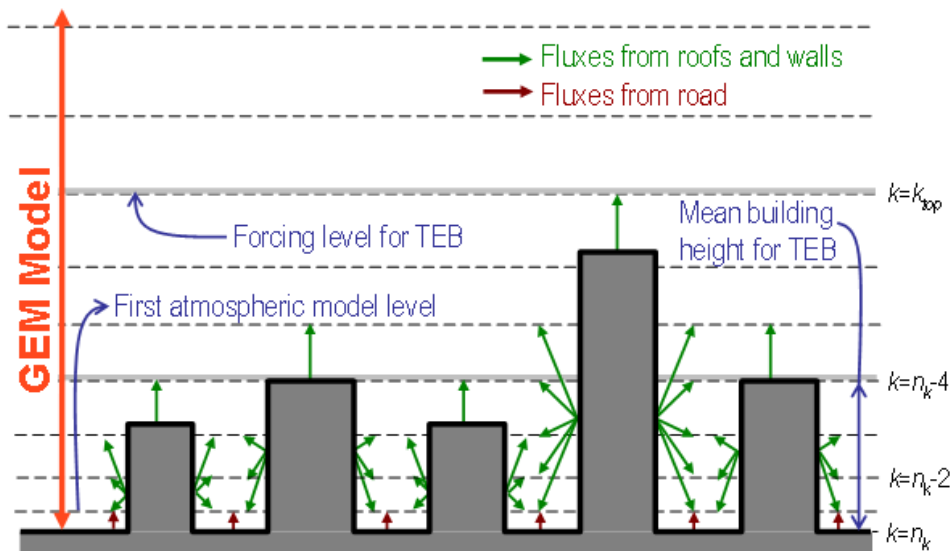
- *CaM-TEB (Canadian Multilayer version of TEB)*

- *Several model levels intersect the buildings.*

- *Variable building heights exist within a grid cell.*
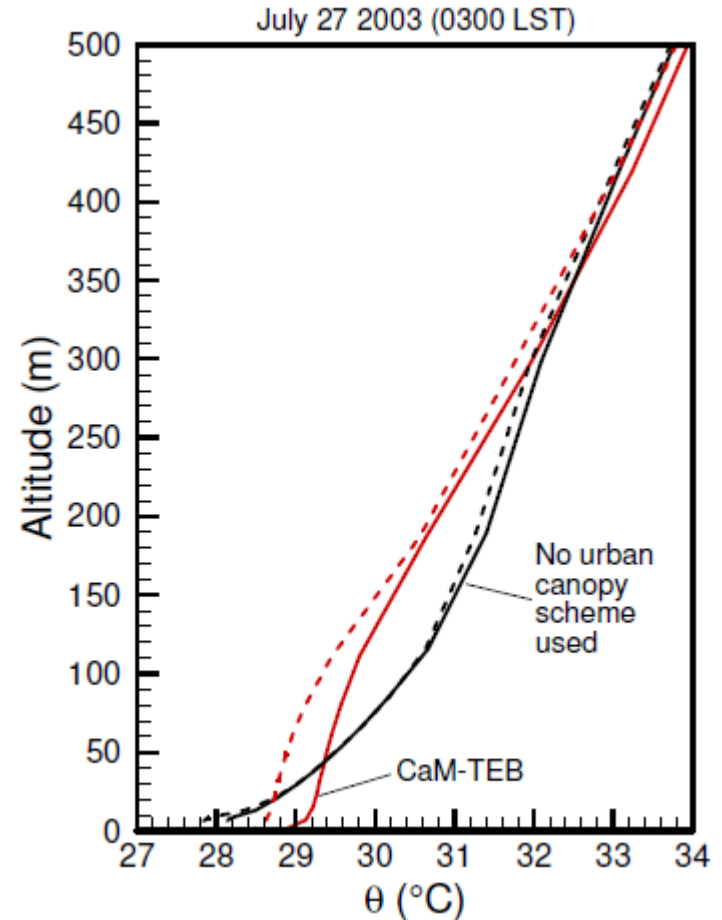
(Husain et al. 2013)

Horizontal Aspect of Coupling

SINGLE GEM (ATMOSPHERE) GRID AREA (LOW RES)

$$\frac{\partial \theta}{\partial t} = \frac{1}{\rho}\frac{\partial}{\partial z}\left(\rho\, K_T\, \frac{\partial \theta}{\partial z}\right) = -\frac{1}{\rho}\frac{\partial}{\partial z}\,\rho\,\overline{w'\theta'}$$

$$\left(\overline{w'\theta'}\right)_S = C_T\, u_i\left[\theta_S^+ - f_S\, \theta_{NK_{atm}}^+\right]$$

$$\alpha_\theta = -C_T\, u_i\, \theta_S^+$$

$$\beta_\theta = -C_T\, u_i\, f_S$$

Spatially averaged

$$-\left(\overline{w'\theta'}\right)_S = \alpha_\theta + \beta_\theta\, \theta_{NK_{atm}}^+$$

SPATIAL AVERAGE OF IMPLICIT LOWER BC FOR VERT. DIFFUSION

WATER

LAND / VEG (ISBA / SVS)

URBAN (TEB)

MULTIPLE SURFACE GRID AREAS (HIGH RES)

Environnement Environment
Canada Canada
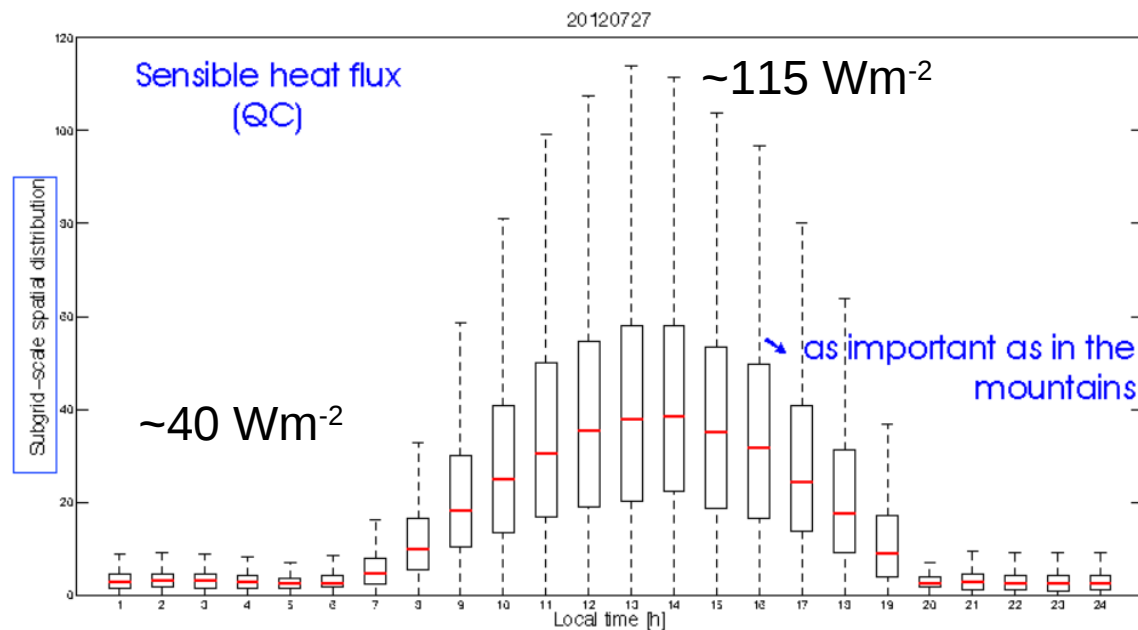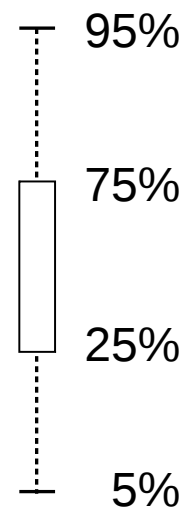Environnement Environment
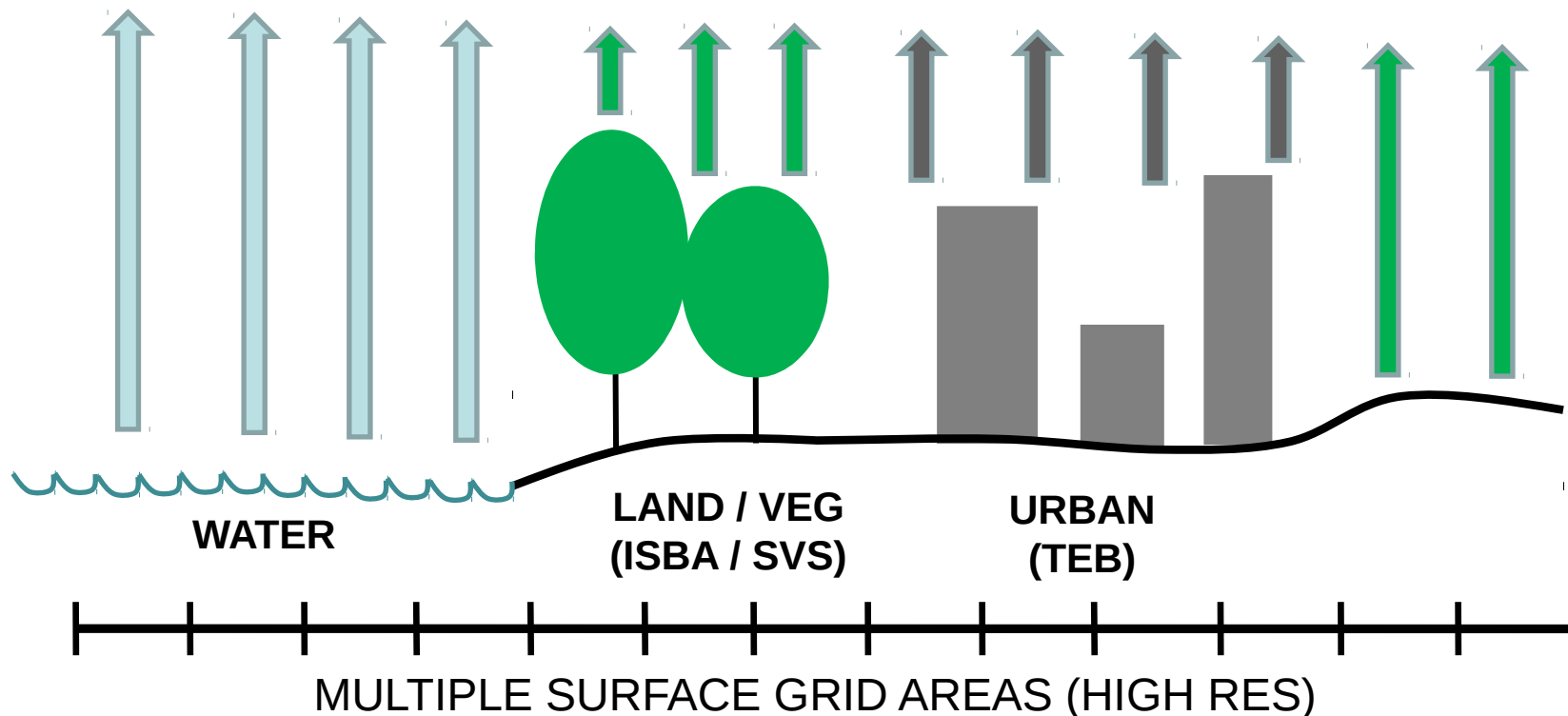
Towards 2-Way Coupling
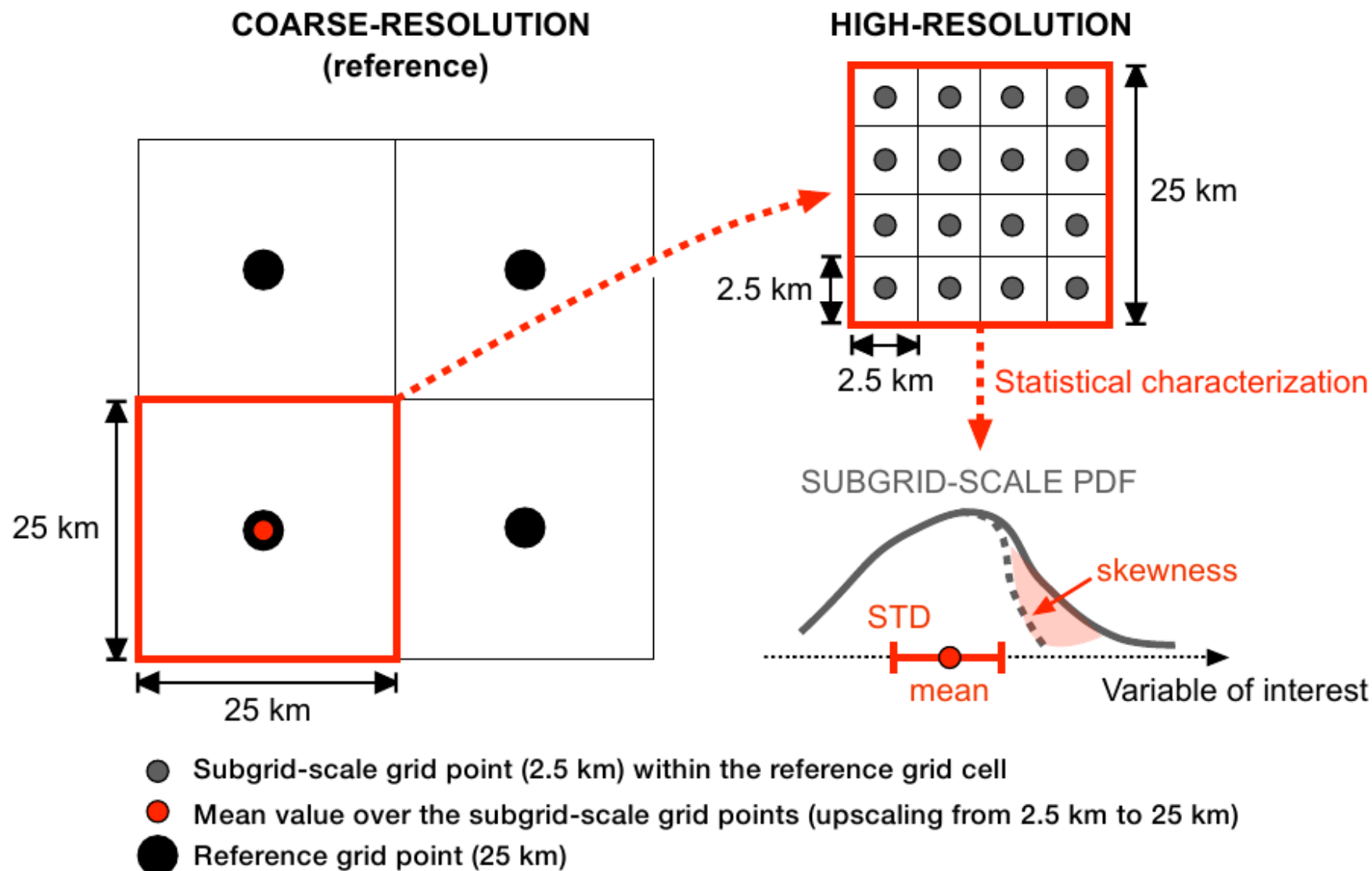
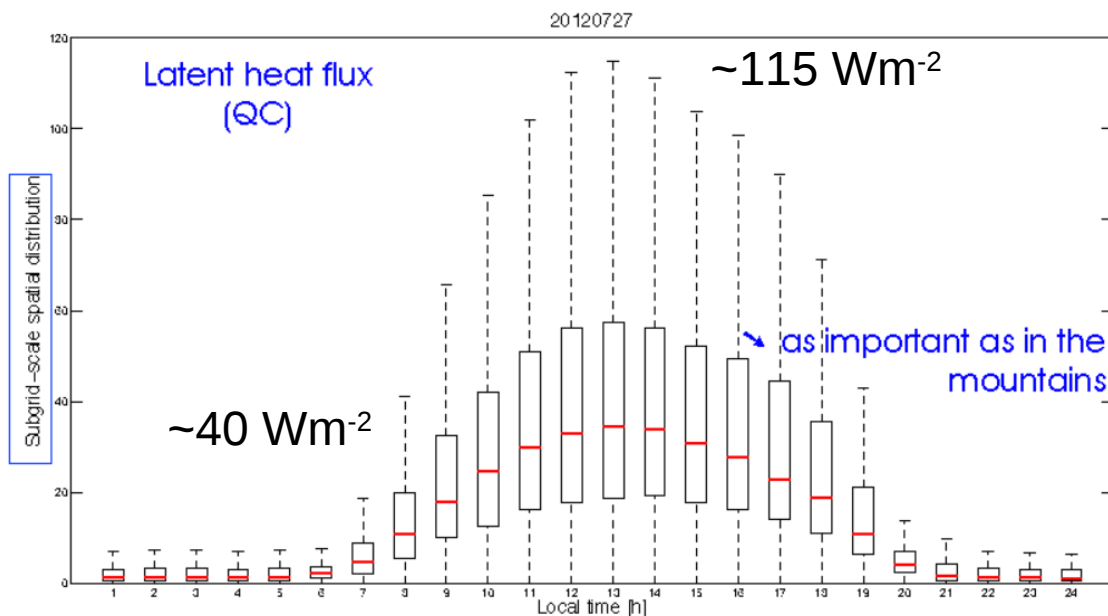(Rochoux et al, 2015, submitted)

Potential Benefit of Two-Way Coupling

(Provided by M. Rochoux, EC)

Subgrid-scale variability of turbulent fluxes for 25-km grid spacing model based on external 2.5-km land surface model

Final Words

An effort much greater than originally expected when this new phase started a decade ago...

All aspects important

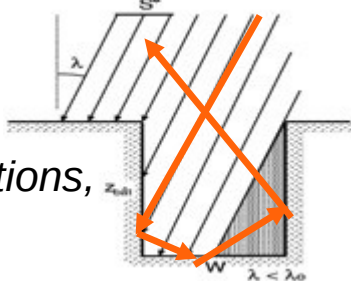*Comments and recommendations are welcome!*

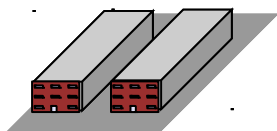# The end... backup slides (urban stuff)

Environnement Environment
Canada Canada

The Town and Energy Balance Scheme

(Masson, 2000)

Street canyon concept :
Drag, radiation budgets
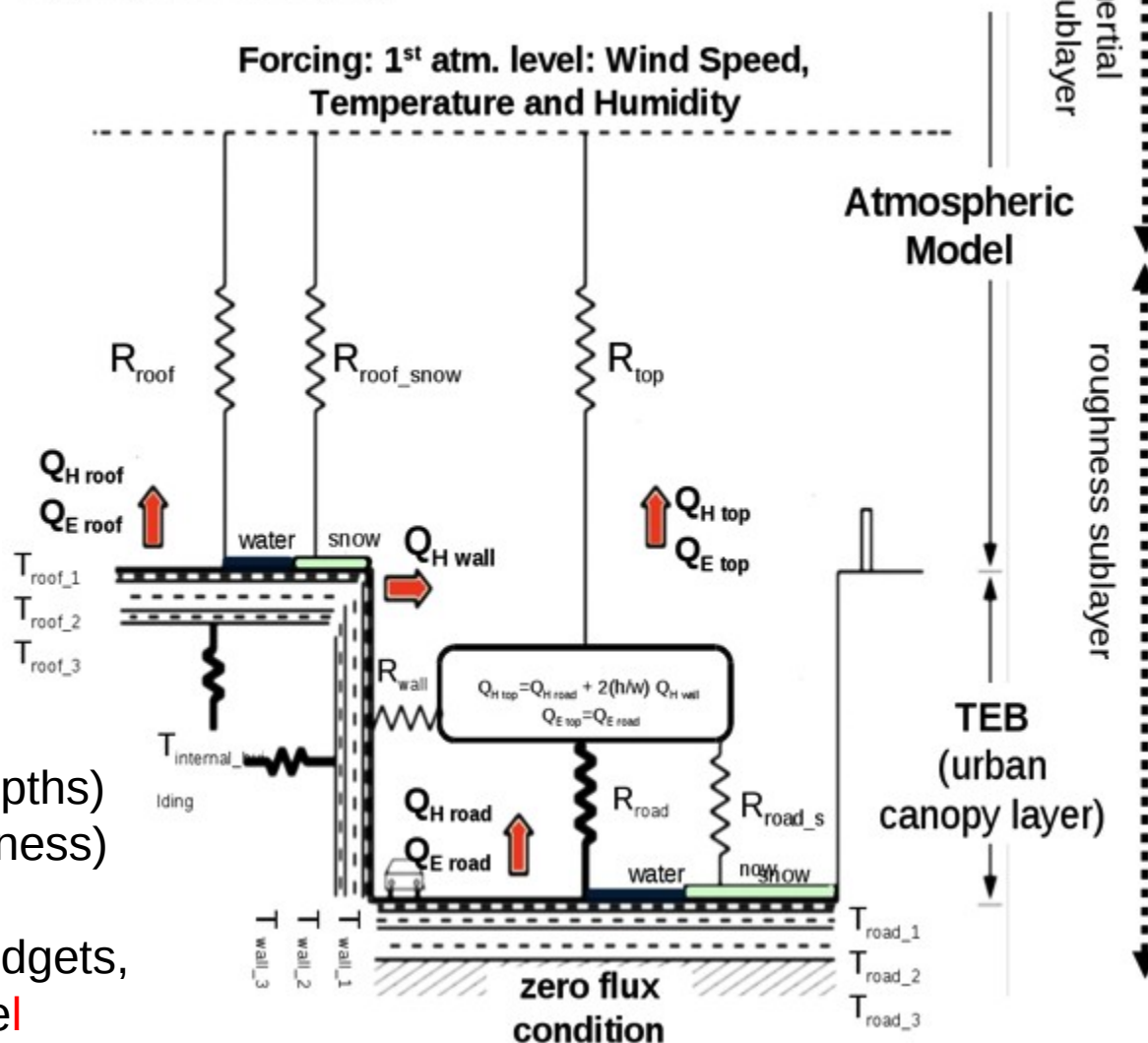
Multiple reflections, trapping absorption
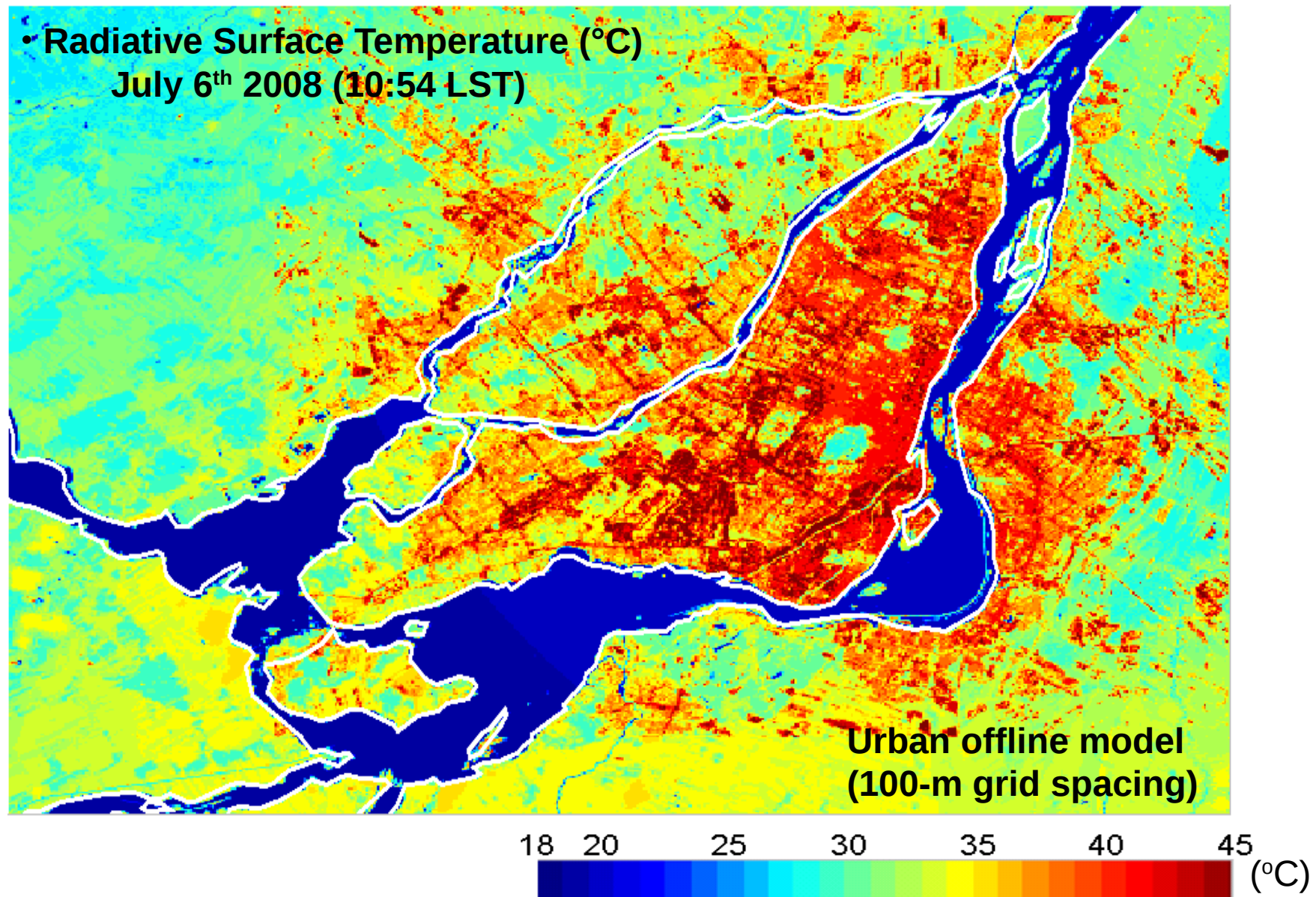
Input:
Urban fabric (material layers, depths)
Morphology (aspect ratio, roughness)
Output :
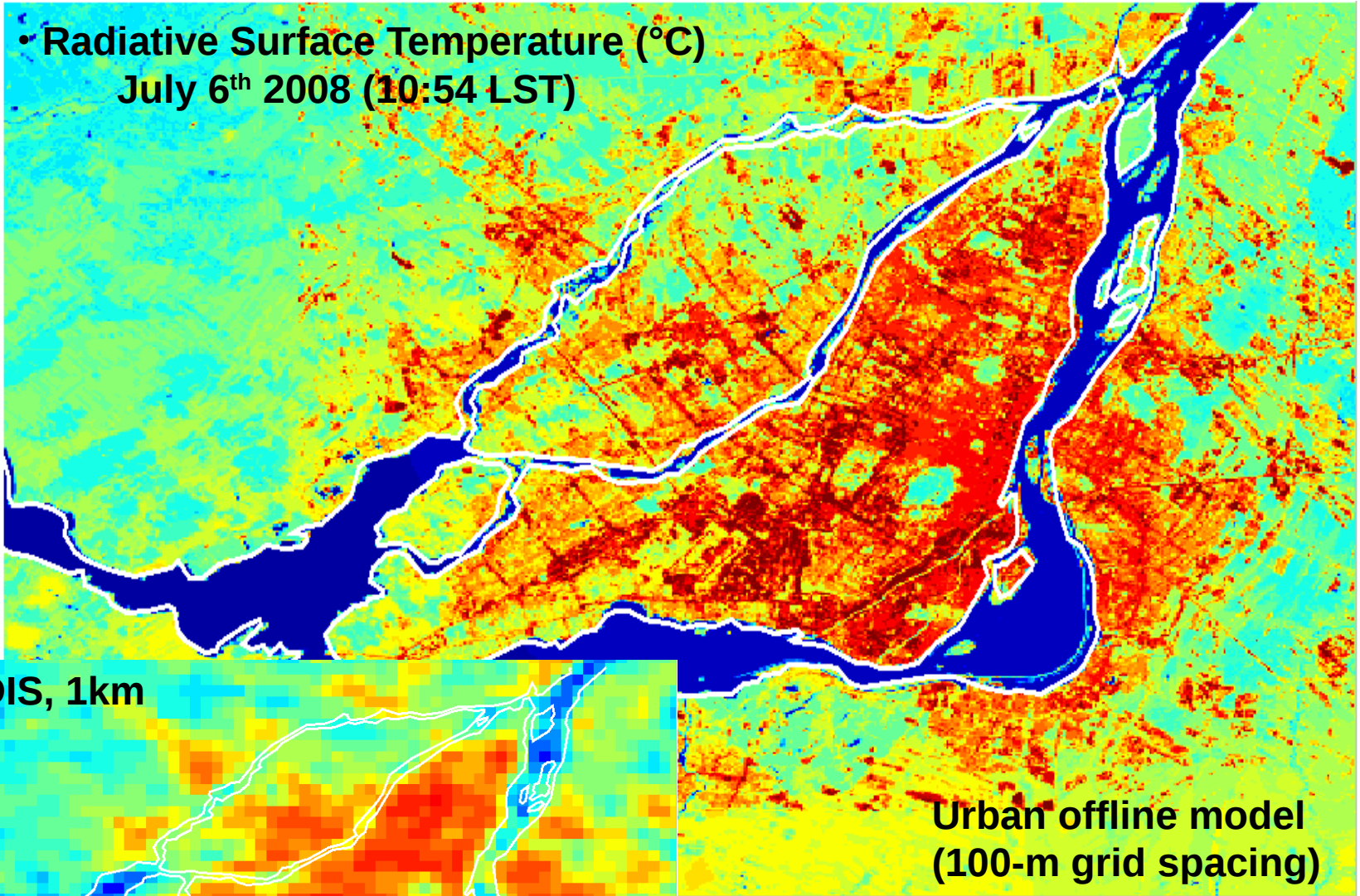Surface temperatures, Energy budgets,
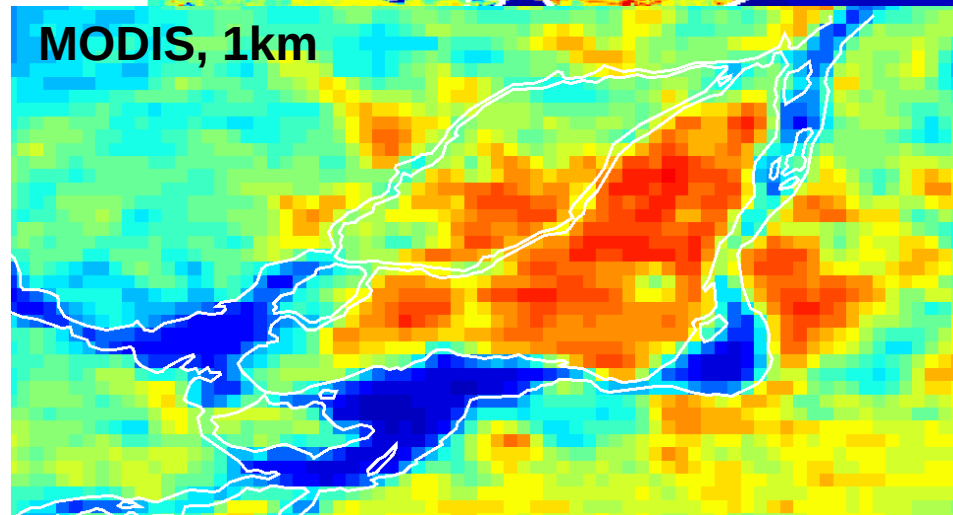T, q, wind at pedestrian level

Image adapted from Masson (2000)

Forcing: 1st atm. level: Wind Speed, Temperature and Humidity

TEB: Urban Heat Islands

- Radiative Surface Temperature (°C)
  July 6th 2008 (10:54 LST)

Urban offline model
(100-m grid spacing)

18 20   25   30   35   40   45

(°C)

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Canada   Canada

(Leroyer et al., 2011)

TEB: Urban Heat Islands

- Radiative Surface Temperature (°C)
  July 6th 2008 (10:54 LST)

MODIS, 1km

Urban offline model
(100-m grid spacing)

25   30   35   40   45

(°C)

(Leroyer et al., 2011)

Tokyo Case: Urban Areas

Radar / Raingauge Analysis (JMA)

GEM - 250m

**19-h Forecast
(with TEB)**
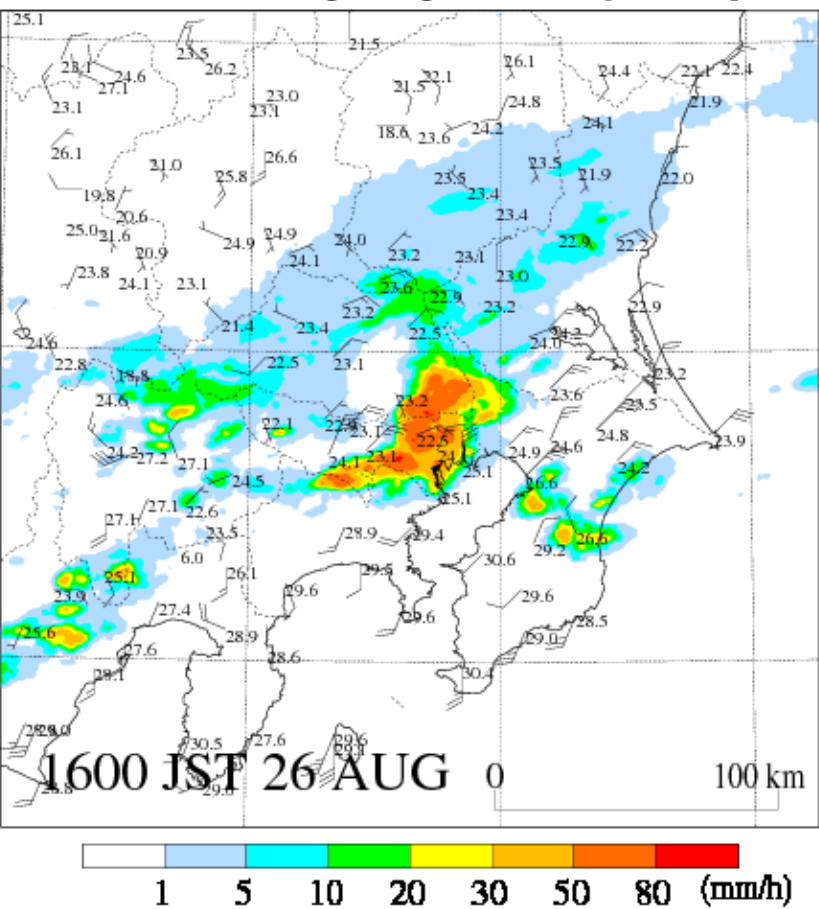
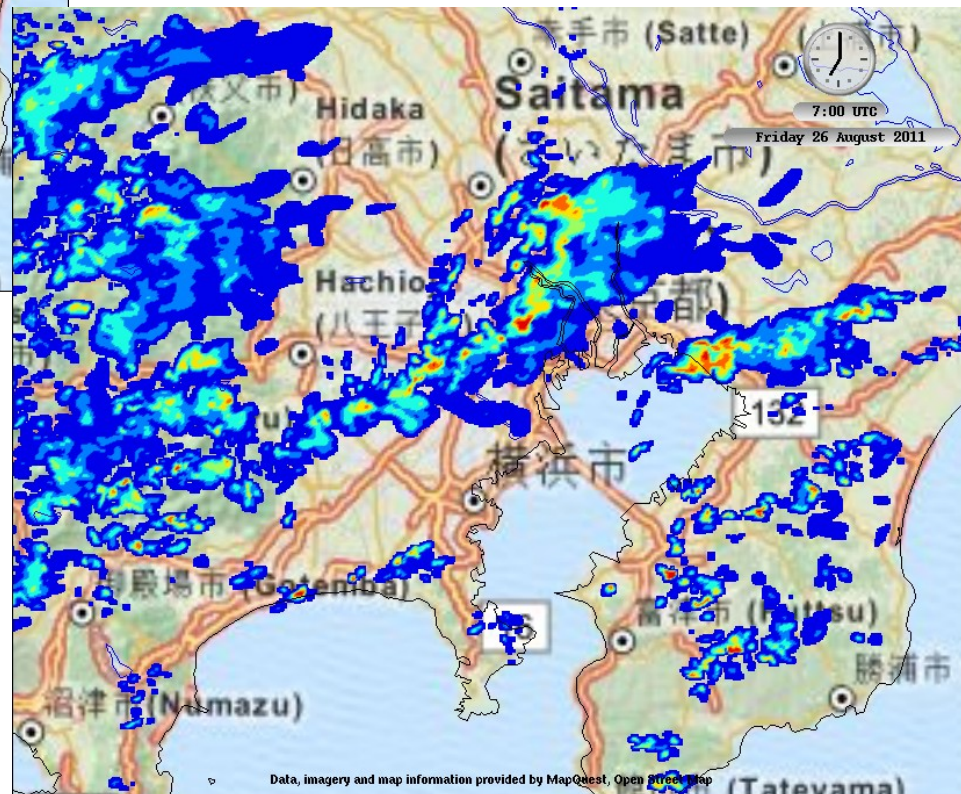(Courtesy of N. Seino, JMA/MRI)

Environnement Environment
Canada Canada
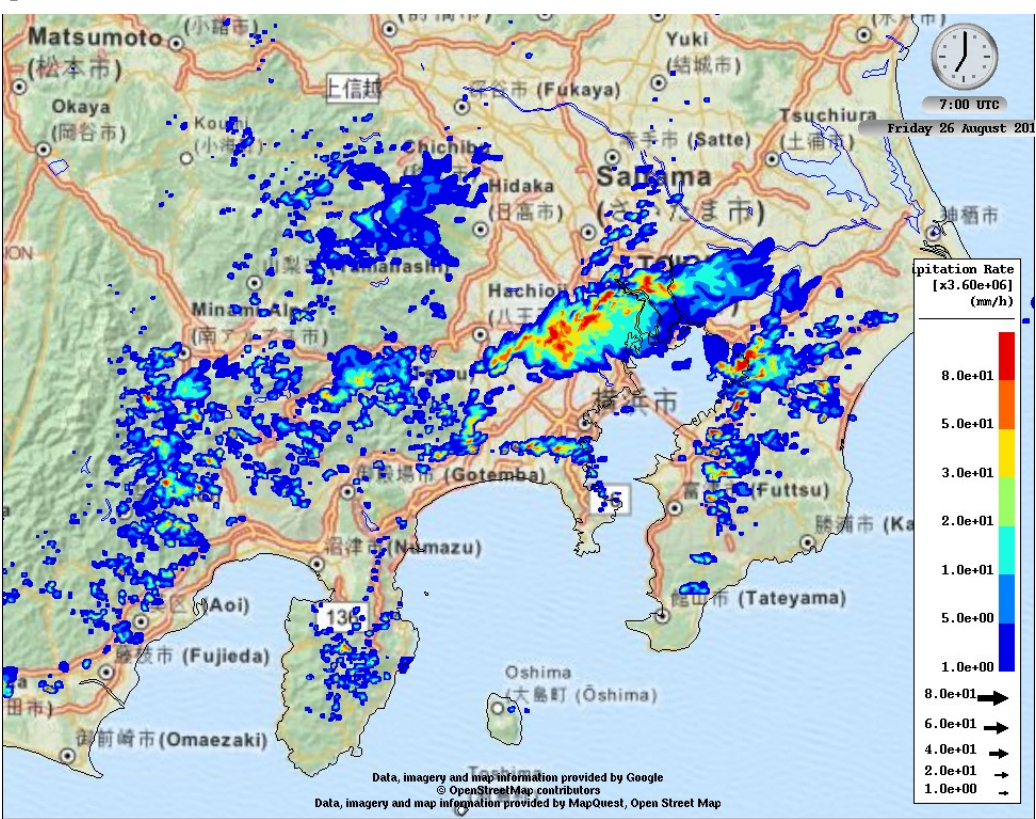
(Lubos Spacek)

Tokyo Case: Impact of TEB
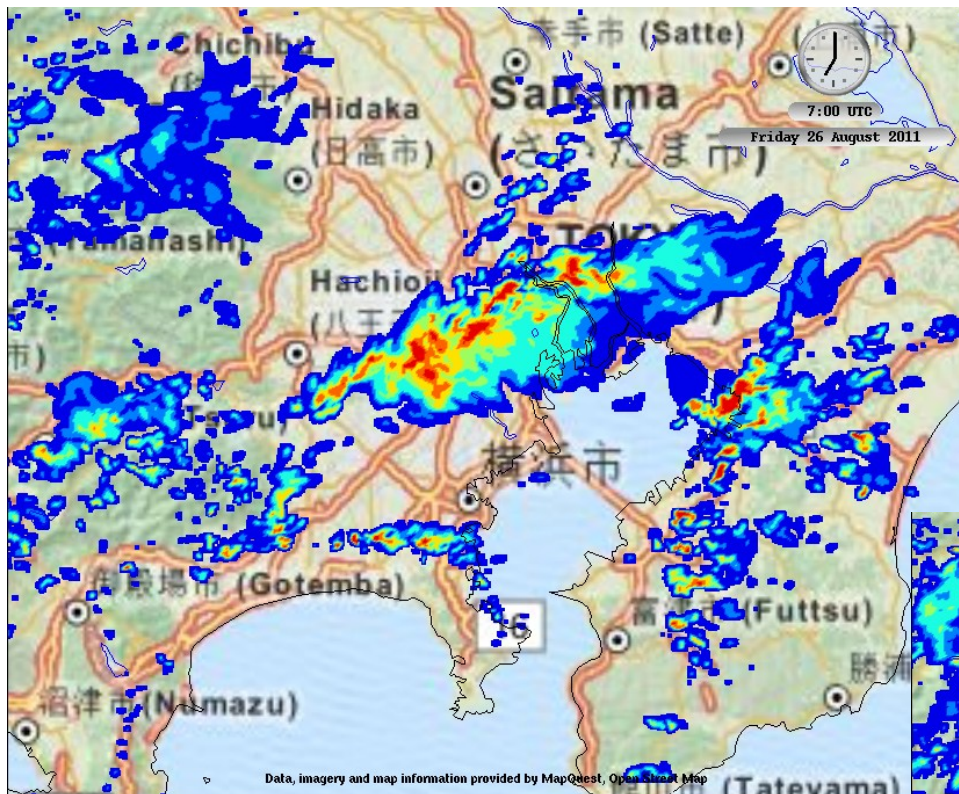
Without URBAN (no TEB)

CONTROL RUN – with URBAN

**19-h Forecast
Valid at 1600 JST
26 Aug. 2011**

Environnement Environment
Canada   Canada

(Lubos Spacek)